ABSTRACT

Sarvak Formation (Cenomanian) from bangestan group is one of the important reservoir units after Asmari in southwest Iran that host an important hydrocarbon reserves in this region. The thickness of Carbonate sequence of Sarvak Formation is 760 m in Ahvaz oil field (well no, 63). This Formation is overlain by the Kazhdumi Formation and is disconformably underlain by the Ilam Formation. Main diagenetic processes effected carbonates of this unit are micritization, dissolution, dolomitization, cementation, neomorphism, compaction and silicification. This study uses thin section descriptions and geochemical analysis to determine diagenesis and original mineralogy of the Sarvak carbonates. Based on major and minor elements (Ca, Mg, Mn, Fe, Na, Sr), Carbon and Oxigen isotope and petrographic studies indicate that aragonite was original carbonate mineralogy. Chemical studies spatially variations of Sr/Ca and $\delta^{18}O$ values versus Mn illustrate that these carbonates were affected by meteoric diagenesis in a nearly closed system. The results show that diagenesis cause rise of Fe and Mn and decrease of Sr/Ca and stable isotope ratios. Temperature calculation based on the heaviest oxygen isotope value of the least-altered sample indicates that seawater temperature was around 27°C during Sarvak deposition.

KEYWORD

Sarvak Formation, diagenesis, geochemistry, Ahvaz oil field, Iran

INTRODUCTION

The Upper Cretaceous Sarvak Formation in southern Iran contains more than 20% oil-in-place of Iranian oil reservoirs, forming the second most important reservoir rocks. In modern tropical warm waters, aragonite is the predominant mineral, along with some high-Mg calcite [1]. Variation in carbonate mineralogy has been related to the position of global sea level [2], changes in rates of seafloor spreading [3, 4], PCO2 level [5, 6, 7] and Mg/Ca ratio related to spreading rate [8]. However, other researchers suggested that the change of original carbonate mineralogy is related to water temperature or latitude [9, 10]. Sr and Mg concentrations in micrites imitate the concentrations in the precursor aragonite or Mg calcite [11], because these elements are incorporated into calcite at equal rates during diagenesis. Meteoric diagenesis is recognized typically with enrichment of Fe and Mn and depletion in Sr and Na [12, 13, 14, 15, 16].

Diagenetic textures in carbonates can give clues regarding the physical and geochemical environment in which diagenesis has occurred. Petrographic evidence and elemental values in the present study have been compared with recent tropical shallow-marine aragonite [1], recent temperate bulk carbonate [17, 18, 19], originally aragonitic Ordovician subtropical carbonates of Tasmania [20], and aragonitic shallow subtropical carbonates of the Upper Jurassic Mozduran Formation of Iran [21], to understand the original carbonate mineralogy and diagenetic characteristics of the Sarvak Formation.

1. Geological setting

The study section (well No.63) is located in Ahvaz oil field, in Khuzestan province in south west of Iran (Fig. 1). This well has nearly perfect core. The Sarvak Formation (Cenomanian) which is part of the Bangestan Group consists mainly of fossiliferous limestone (Fig. 2). The type section of the Sarvak Formation is situated in the Teng-e-Sarvak area, Khuzestan, and is overlain by the Kazhdumi Formation and underlain by the Ilam Formation, Like in the study area. The boundary between Sarvak and Ilam Formation is a disconformity that determined in some area by breccia or conglomerates.
The thickness of the Sarvak Formation in the study area is 760 m and it consists of two major facies (neritic and pelagic). The neritic facies includes a massive limestone containing algae, echinoderms, rudists, gastropods and bivalves and is rich in micro fauna. The pelagic deposits are contain abundant oligostegina [22]. Sarvak Formation was deposited on the passive margin which existed in the east of the Arabian craton throughout much of the Mesozoic. This passive margin was generally covered by shallow waters, however, a number of deeper-water intera shelf basins had been formed during the Cretaceous [23]. Rudist-bearing units in the upper Sarvak Formation were deposited in carbonate ramps and low-gradient shelves which rimmed these basinal areas [24].

2. Methods of study

About two thousand uncovered thin sections were studied for petrographic analysis. Thin sections were stained by potassium ferricyanide and alizarin-red solution to distinguish ferron and nonferron calcite from dolomite [25]. Twenty eight powdered micritic samples were analysed by atomic absorption spectrometer for Ca, Mg, Sr, Na, Mn, Fe at the Geology Department of the Shahid Beheshti University, Tehran, Iran. Precision was ±0.5% for Ca and Mg and ±5 ppm for Sr, Na, Mn and Fe [26]. Nine powdered samples which had previously been analysed for major and minor elements were analysed with a Micromass, 602D for oxygen and carbon isotopes at the Central Science Laboratory, University of Tasmania, Australia. A dentist drill with a stainless steel circular bit was used to collect samples for geochemistry. Fifteen mg of powdered samples were allowed to react with anhydrous phosphoric acid in reaction tubes under vacuum at 25°C for 24 h. The CO2 extract from each sample was analysed for δ18O and δ13C by mass spectrometry. Precision of data is ±0.1‰ for both δ18O and δ13C and these values were reported relative to PDB.

3. Diagenesis

The Sarvak Formation has been subjected to extensive and variable diagenetic modifications after its deposition in a shallow-marine environment, during subaerial exposure and subsequent burial. Diagenesis in the Sarvak Formation included seven major processes: 1) micritization; 2) cementation; 3) neomorphism; 4) physical and chemical compaction; 5) dissolution; 6) dolomitization; and 7) Silicification.

- Micritization

Micritization identified here is an early diagenetic process. Micritic envelopes surround some rudist and echinoderm fragments, and wholesale micritization of some benthic foraminifers in bioclastic packstone or grainstone microfacies makes the recognition of skeletal grains difficult in some intervals (Fig 3-A).
- Cementation

Different generations of sparry calcite cement were recognized in the Sarvak limestone, ranging from marine through meteoric to some burial cement. Marine cements are fibrous and occur as intra and inter granular cements. Isopachous cements form fringes around grains (Fig. 3B). These cements were possibly composed of aragonite, due to the identical morphology to that of recent Warm-water shallow-marine aragonitic cements [27, 15].

In the Sarvak limestones, bladed calcite cements occur both interparticle, and within fractures (Fig. 3C). Individual crystals often show bladed crystal morphology with scalenohedral terminations. The bladed cement in the Sarvak limestones is commonly followed by a later generation of equant, drusy calcite. Syntaxial or epitaxial overgrowth cements grow as single crystals on echinoderm grains.

- Neomorphism

A number of neomorphic fabrics occur in the Sarvak Formation. Micrite and pseudomicrite commonly replace micrite in muddy carbonates (Fig. 3D).

- Compaction

Both mechanical and chemical compactions are observed in the Sarvak Formation. Mechanical compaction resulted in porosity reduction by breakage of the grains in packstones. Dissolution seams and stylolites are among the most common chemical compaction features in most of the rock units within the Sarvak succession (Fig. 3E).

- Dissolution

Dissolution was one of the diagenetic processes to affect the porosity and permeability in the Sarvak carbonates, especially in grain-supported intervals. There are evidences for dissolution features and matrix in the limestones of the Sarvak Formation. Limestone dissolution adequate for creating commercial reservoirs is restricted to processes associated with dolomitization and cementation that filled the most of porosities.

- Dolomitization

Four types of dolomite are recognized in the Sarvak Formation; (1) fine-very fine crystalline (16-76 µm) dolomite replacing unfossiliferous or scarcely fossiliferous mudstone often with irregular fenestral voids (dolomite I); (2) euhedral Fine to medium crystalline (37-210µm) dolomite replacing carbonate matrix with Fe-oxide zonation in rims (dolomite II); (3) compaction-associated Subhedral to anhedral medium crystalline (62-250µm) dolomite with a cloudy centre and clear rim (dolomite III), replacing the carbonate matrix or recrystallization of last types (Fig. 3F). (4) anhedral Coarse crystalline dolomite with variably large crystal sizes (200-1100 µm), as void filling cement (dolomite IV) (Fig. 3G).

- Silicification

Minor silica precipitation partially replaces some of the calcitic bioclasts and the latest fracture-filling blocky calcite cements (Fig. 3H). The silica was probably provided by the dissolution of sponge spicules, which are common in the intervals representing the outer ramp environment of the Sarvak Formation.

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Fig. 3: (A) Micritization on bivalve shell, (B) Isopachous fibrous cement around intraclasts, (C) Drusy cement in fracture, (D) Neomorphism process, (E) Chemical compaction and stylolites crossing each other, (F) Dolomite type III, (G) Dolomite type IV filling fracture, (H) Silicification.
4. Geochemistry

4.1. Major and minor elements

- Strontium

The Sr content varies due to carbonate mineralogy. Sr increases with increasing aragonite content [15] and decreases with increasing calcite content. Concentrations of Sr have also been directly related to increasing water temperature [28].

The concentration of Sr in the Sarvak limestone samples ranges from 483 to 840 ppm (Fig. 4A). Sr values of these samples are lower than those of their modern counterparts, due to progressive loss of Sr during meteoric diagenesis [15].

- Sodium

Sodium concentrations in carbonate sediments are related to salinity, biological fractionation, kinetics, mineralogy and water depth [17, 29, 30].

Concentration of Na in the Sarvak limestone samples ranges from 99 to 375 ppm, with a mean of 224 ppm (Fig. 4A). Na values are lower than those of modern warm-water aragonitic counterparts; because Na has partition coefficient of <1, and there is a low concentration in meteoric waters [15].

The plot of Sr–Na values shows that most limestone samples fall within subtropical warm water aragonitic Ordovician Gordon limestone field [20].

- Manganese and ferrum

The concentration of Mn in the Sarvak limestone samples ranges from 15 to 35 ppm with a mean of 21 ppm. Also Fe concentration varies from 75 to 297 ppm (mean 185 ppm). In modern warm-water aragonite, Mn and Fe concentrations are less than 20 ppm [1].

The Sr/Na–Mn variations show that some samples fall in the aragonite field (Fig. 4B). The low Mn and Fe concentrations in this Formation may indicate an original aragonite mineralogy.

Changes in the value of Sr, Na and Mn, indicate two stages of diagenetic stabilization [15]. In the first stage, Sr and Na changes significantly, but Mn values remain constant. This is due to conversion of aragonite to low-Mg calcite. In second stage of diagenetic stabilization followed by significant increasing in Mn and little change in Sr and Na values mainly as result of the meteoric diagenesis.

This process led to recrystallization of low Mg calcite and increasing of spary calcite cement that controlled Mn values [13, 14, 31].

- Sr/Na ratio

Modern and ancient tropical carbonates differ from their non-tropical counterparts by their Sr/Na ratio and Mn contents [20, 32]. In the Sarvak limestone (Fig. 5A), Sr/Na concentrations range from about 2 to 6 (mean ~3); Similarity of the trace-element data with modern and ancient carbonates support the interpretation that the Sarvak Formation limestone were originally aragonitic warm-water carbonates.

- Sr/Ca ratio

By plotting Sr/Ca versus Mn, the close or open meteoric diagenetic systems can be recognized [33].

The bivariate plot of Sr/Ca versus Mn in Sarvak carbonates shows that the limestones have been stabilized by fluids in a closed to semi-closed diagenetic system [13] (Fig. 5B).

Fig. 4: (A) Sr and Na variations in the Sarvak Formation. Note that all data falls within the aragonite fields due to similar mineralogy. (B) Sr and Mn variation in the Sarvak limestones. Some sample fall out of Mozduran and Tasmania aragonite fields due to less meteoric diagenesis in Sarvak Formation.
- Sr/Mn ratio

Sr/Mn ratio used as useful criteria for estimating solubility of limestones [20, 34]; Because of solubility of aragonite and high-Mg calcite and conversion those to low-Mg calcite, Sr values significantly reduced and Mn concentration increased. This process is common in meteoric diagenetic environments [35]. The high Sr/Mn content in Sarvak limestones, compared to Ordovician Gordon Group [20] and aragonitic Mozduran [21], fields indicate that Sarvak limestones have been affected by meteoric diagenesis in a close to semi-closed system (Fig. 4B).

4.2. Oxygen and carbon isotopes

The value of Oxygen isotope in the Sarvak limestone ranges from -3.52‰ to -6.4‰ PDB (mean -4.77‰ PDB), whereas δ^{13}C value range from 1.67‰ to 2.85‰ PDB (mean 2.16‰ PDB, Fig. 5C). The δ^{18}O values of diagenetic carbonate phases are mainly controlled by fluid composition, temperature and water/rock ratios [13], and consequently the δ^{18}O values are expected to be reset by diagenetic alteration. δ^{18}O – δ^{13}C values from the Sarvak Formation suggest diagenetic alteration in a marine phreatic setting.

It is important to note that most samples fall within the Cretaceous marine isotopic fields, indicating similar age, and minor diagenetic effects.

Bivariate plots of trace elements versus carbon and oxygen isotope values were used to determine original carbonate mineralogy.

**Fig. 5:** (A) Bivariate plot of Sr/Na versus Mn. Note the Sr/Na ratio of all samples are >1, indicating original aragonite mineralogy. Some data also fall within the recent warm-water aragonite field due to similar mineralogy. (B) Mn and Sr/Ca variation in the Sarvak carbonates. The trend shows that these carbonates were affected by marine phreatic fluids in a closed to semi closed diagenetic system. (C) The δ^{18}O and δ^{13}C variation in the Sarvak carbonates. All samples fall in cretaceous marine limestone near Mozduran aragonite field. (D) Variations of δ^{18}O value versus Mn. Note the most of Sarvak samples fall in Ordovician aragonite or near it because of similar mineralogy.
5. Determination of water temperature
The least-altered carbonate sample, with a δ18O value of -3.8‰ PDB, was used to calculate a temperature during the relatively shallow burial, using the equation of Anderson and Arthur, 1983 [36]:

\[ T(°C) = 16 - 4.14(\delta_C - \delta_W) + 0.13(\delta_C - \delta_W)^2 \]

Where T is temperature (in °C), δC is the heaviest oxygen isotope value in studied samples and δW is the oxygen isotope value of marine water in the Cretaceous (in SMOW), i.e. -1‰ SMOW [37]. This calculation gives an early shallow burial fluid temperature of about 27º C.

6. Conclusions
In this study, Results of Petrographic and geochemical studies of the Sarvak Formation in southern Iran, Zagros basin can be summarized as follows:
1. Petrography studies showed main diagenetic processes effected carbonates are micritization, dissolution, dolomitization, cementation, neomorphism, compaction and silification.
2. Bivariate plots of minor and major elements, oxygen and carbon isotope values indicate that the original carbonate mineralogy was dominantly aragonite in the Sarvak Formation.
3. Variations of δ18O values versus Mn and Sr/Ca versus Mn suggest that the Sarvak carbonates were stabilized in the marine phreatic environment.
4. Sr/Mn and Sr/Ca ratios indicated that Sarvak limestone affected by diagenetic processes in a closed to semi-closed system.
5. Sea water temperature during Sarvak carbonate deposition is indicated around 27 ºC based on the heaviest oxygen isotope value.

REFERENCES


