PETROFACIES AND SEQUENCE STRATIGRAPHY OF THE QOM FORMATION (LATE OLIGOCENE-EARLY MIOCENE?), NORTH OF NAIN, SOUTHERN TREND OF CENTRAL IRANIAN BASIN

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ABSTRACT: The Qom Formation (Late Oligocene-Early Miocene?) to the north of Nain along the southern trend of the central Iranian Basin represents a carbonate-marl depositional system. Upward, the predominant microfacies are sandstone (litharenite); reworked lithobioclastic grainstone, bioclastic packstone to wackestone with the larger benthic foraminifera and mollusks; bioclastic packstone to wackestone with the smaller foraminifera; bryozoa grainstone; and peloid and miliolid wackestone.

Microfacies analysis and facies interpretations suggest that the dominant environments were marginal to restricted open marine, open marine to restricted marine and bar; and open marine to lagoon and nearshore.

Three depositional sequences were also recognized. These sequences are characterized by the retrograding and aggrading stacking patterns of transgressive and highstand system tracts, respectively. A marginal prograding stacking pattern of lowstand system tracts was also recognized at the base. Sequence boundaries were characterized by either an abrupt change in lithology or by superposition of transgressive beds upon aggrading ones. Maximum flooding surfaces were coincident with deepening and shallowing in each depositional sequence.

INTRODUCTION

The Qom Formation in Central Iran was introduced by Tietze (1875) and Stahl (1911). It was referred to as a limestone, marl and marly limestone occurring between the continental deposits of the Lower Red Formation and Upper Red Formation.

The type section of the Qom Formation is introduced and defined in the Qom area by Furrer and Soder 1955; Bozorgnia 1966; Stocklin 1968. Based on its microfauna, the Qom Formation is Middle Oligocene-Early Late Miocene (Rupelian-Burdigalian) in age (Bozorgnia 1966; Kalantary 1986). Investigations of the Oligo-Miocene deposits in central Iran include the geology and petrography of the area north of Nain (Davoudzadeh 1972); the Oligo-Miocene and Pliocene in Iran (Rahimzadeh 1994); the stratigraphy, micropaleontology and petrography of the rocks in Natanz and Anarak (Sajjadi 1990); and the Oligo-Miocene shallow-marine biofacies of central Iran (Hamedani et al. 1998). In this study the microfacies, paleoenvironment and sequence stratigraphy of the Qom Formation to the north of Nain, far from the central Iranian Oligo-Miocene depocentre (Qom area) is examined.

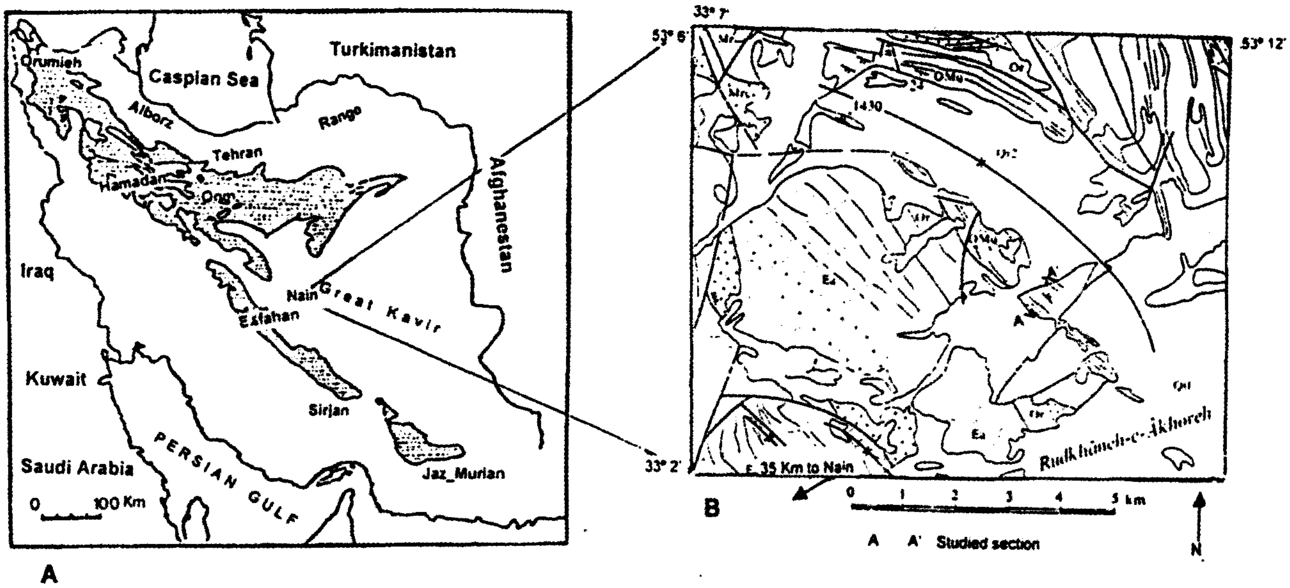
REGIONAL ASPECT

The Qom Formation was mostly deposited in a backarc basin in the central and northern part of the central Iran during the Late Oligocene (Berberian 1983). Subduction of the Neotethys (Zagros oceanic crust) and southwestern Iranian cratonic plate led to backarc spreading. Due to a northeast-southwest marine transgression, the age of the Qom Formation varies. It ranges from late Oligocene to Early Miocene. Variation in thickness and lithology indicates that the Qom Formation was deposited in various positions within the Qom backarc basin (Schuster and Wielandt 1999). Vertical positive and negative movements may have controlled the thickness and lithofacies variations seen within the Qom Formation (Nogol-e-Sadat 1985). Despite the vast marine cover of central Iran by an epicontinental sea, which was caused by a decrease in the depth of deposition, many paleogeomorphic highs remained mostly out of water. As a result, deposition in central Iran occurred in a shallow environment with many intermountane basins. Fluvial, shallow carbonate evaporite, carbonate-marl and deeper carbonate deposition is common within the Qom Formation. It is considered a time equivalent of the carbonate facies of Asmari Formation of southwest Iran, the salt-bearing carbonate–terrigenous series of Soviet Nakhichevan Formation, and the marine deposits in northeastern Anatolia (Stocklin and Setudehnia 1977). The Qom Formation is also the main objective of oil and gas exploration in Central Iran.

The eastern exposures of the Qom Formation in central Iran are along the northern and southern parts of the Great Kavir where it passes eastwardly into a red gypsiferous marl and the sandstones of the Lower and Upper Red formations. The northern exposure of the Qom Formation is coincident with the foothills of the Alborz Range. It is also present along the Lake Orumieh region in the far northeast. The southwestern extension of the Qom Formation is well developed in the Saveh-Hamadan region where it is up to 2000 m thick. The southwestern limit of the Qom Formation outcrops is coincident along with Orumieh-Hamadan-Esfahan-Sirjan-Jaz Murian trend (Stocklin and Setudehnia 1977), Fig. 1A.

The thickness of the Qom Formation at its type section in the Qom area is about 1200 m. Six members (A-F) and four submembers (C1-C4) are idenitified at the type locality (Fig. 2). Member A consists of massive to thick-bedded organodetrital limestone. Member B is characterized by marl, sandy marl and sandstone. Submember C1 is

Carbonates and Evaporites, v. 20, no. 1, 2005, p. 82-90.



SYSTEM	SYMBOL	LITHOLOGY	FORMATION
QUATERNARY	Qt2	Younger gravel fans and terraces	
	Qt1	Older gravel fans and terraces	
MIOCENE — PLIOCENE	Mr, Mrc	Sandstone and marl: red and gray Mrc: conglomerate	UPPER RED FORM.
OLIGO — MIOCENE	OMq, OMs	Limestone and sandy limestone OMs: sandstone	QOM FORMATION
EOCENE — OLIGOCENE	Or	Conglomerate and sandstone, red Sandstone and marl	LOWER RED FORM.
	Ea	Sandstone, shaly sandstone, graywacke, and conglomerate Basal conglomerate	ĀKHOREH FORM.

Figure 1. (A) Regional distribution of the Qom Formation in Iran (adapted and revised from National Iranian Oil Company Geological maps). (B) Geological map and location of the study area (adapted from Geological Survey of Iran, Nain map).

an organodetrital limestone alternating with marl; C2 a red, gray sandy marl; C3 an algal limestone; and C4 a marly limestone. Member D contains primary gypsum and red shales. Member E is sequence of gray to green marls containing planktonic and non-planktonic fauna and member F is a massive limestone with corals (Fig. 2).

STUDY AREA AND METHODOLOGY

The study area is located 35 km north of Nain and 170 km east-northeast of Esfahan (Fig. 1B). Field work focused on the outcrops of the Qom Formation, 2 km southeast of Abass Abad village. Sections were measured in detail at 33 4'21"N, 53 10'20"E. The thickness of the measured Qom Formation is 263 m. Samples were taken from the carbonate and marly layers almost every meter according to facies variation. For the textural classification of porosity see Choquette and Pray (1970); for the classification of carbonate rocks see Dunham (1965), Flügel (1982); Carozzi (1989), and Wright (1992); for the description of the foraminiferal genera and their classification see Loeblich and Tappan (1988); and for a discussion of the environment of deposition see Scholle et al. (1983), Wilson (1986), Mial (2000) and Geel (2000).

BIOSTRATIGRAPHY

The following microfossils were identified in the limestones of the Qom Formation north of Nain: *Archaias* sp., *Peneroplis* sp., (*Peneroplis evolutus* and *Peneroplis thomasi*), *Rotalia* sp., *Dendritina rangi*, *Tubucellaria* sp., *Quinqueloculina* sp., and miliolids. Coralline algae, mollusk and coral debris were also observed (Plates 1 and 2). Macrofossils were observed in the marls and marly limestones of the Qom Formation. These are Turritella, Cerithium, Spondylus, Pecten, Chlamys, echinoids, oysters and bryozoa (Plates 2 and 3). Based on these fauna, the outcrops of the Qom Formation in the study area are Late

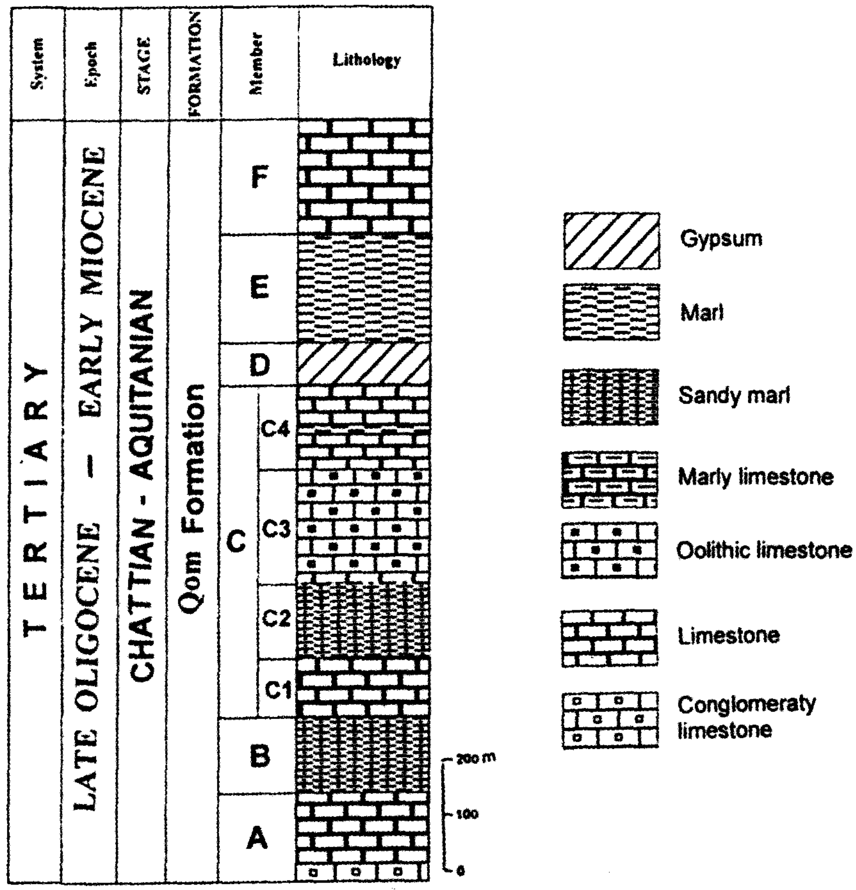


Figure 2. Schematic view of the Qom Formation at its type locality in Qom.

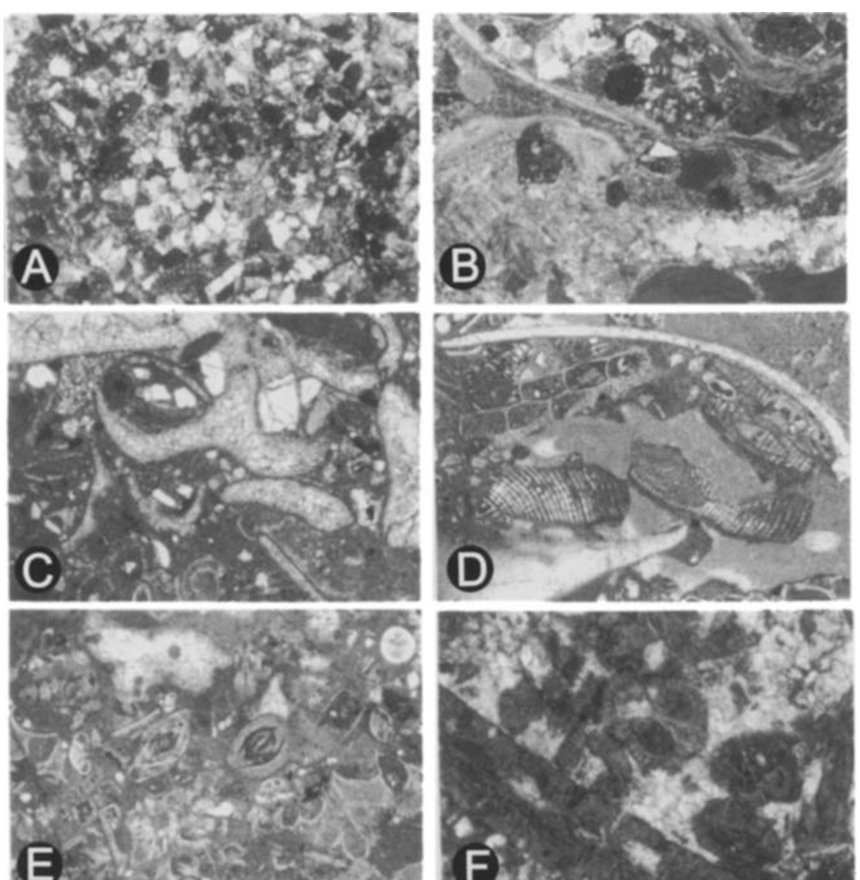


Plate 1. Photomicrographs (x23) of: (A) sandstone (litharenite), quartz sands, feldspar, opaque and micaceous minerals laid down in oxidized calcareous cement, PL (Polarized Light). (B) Lithobioclastic grainstone, mollusk shell and poorly reworked quartz make the framework, PL. (C) Lithobioclastic packstone, reworked micritc coated mollusk shells and poorly-sorted quartz grains laid down in micritic matrix, LN (Natural Light). (D) Bioclastic packstone to wackestone, reworked particles of benthic forminifera, (E) Miliolid packstone, miliolids, bryozoa and small particles of coralline algae laid down in micritic matrix, PL. (F) Bryozoa grainstone, bryozoan particles within coarse crystalline calcite, LN.

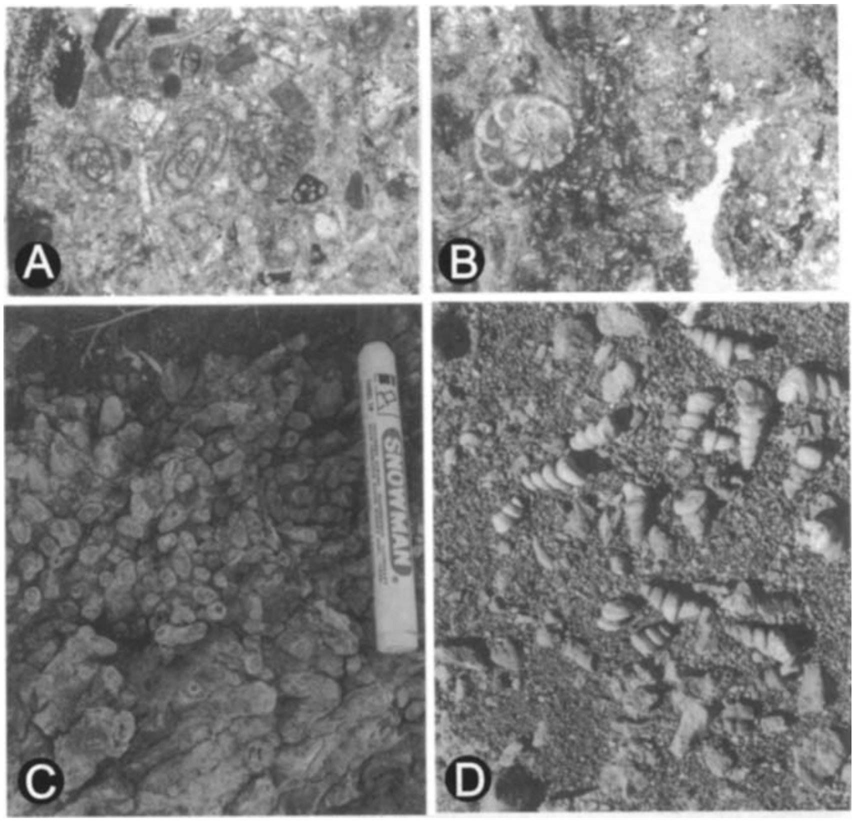


Plate 2. (A and B), Photomicrographs (x23) of Dendritina rangi, Rotalia sp., miliolids and particles of coralline algae and benthic foraminifera associated with micritic to microsparitic matrix, Natural Light. (C and D), Photographs of an exposure of bryozoa at the upper aprt of the Qom Formation and concentration of Turritella associated with the lower part of the Qom Formation.

Oligocene-Early Miocene (Aquitanian)? in age.

MICROFACIES

Sandstone (Litharenite, Andesitic Type)

Quartz sands (50-60 %), altered feldspar (20-25 %) opaque minerals (5-10 %) micaceous minerals (1-5 %) were laid down in an oxidized calcareous cement. Grains are angular and the matrix is poorly sorted. The maximum grain size is about 1.0 mm.

Lithobioclastic Grainstone to Packstone

Mollusk shells and poorly reworked quartz grains comprise the framework. Abraded particles of previously formed mudstone and skeletal grains (bryozoa) are also present. The fabric is poorly sorted. Lithoclasts and bioclasts occur within a micritic and microsparitic matrix. In some instances, coralline algae, bryozoa, mollusks, and echinoid particles make the framework. Abraded skeletal grains with intragranular pores and stylolites are iron stained.

Lithobioclastic Packstone

Reworked micritic coated mollusk shells and poorly-sorted quartz grains were deposited in a micritic matrix. Other bioclasts include bryozoan and miliolids

Bioclastic Packstone to Wackestone

The predominant grains are fragments of reworked mollusks, bryozoa, and benthic forams (*Archaias* sp., and *Peneroplis* sp.). Smaller foraminifera and pelagic? foraminifera, miliolids and echinoids as well as scattered fine sand grains are also present throughout the matrix.

Wackestone to Packstone

Smaller benthic and pelagic foraminifera and fine sand particles were laid down within a micritic matrix.

Bioclastic Bryozoa Packstone

Bryozoa constitute the framework. Particles of gastropods, rotalids, benthic foraminifera are also present. These skeletal grains are in micritic matrix.

Bryozoa Grainstone

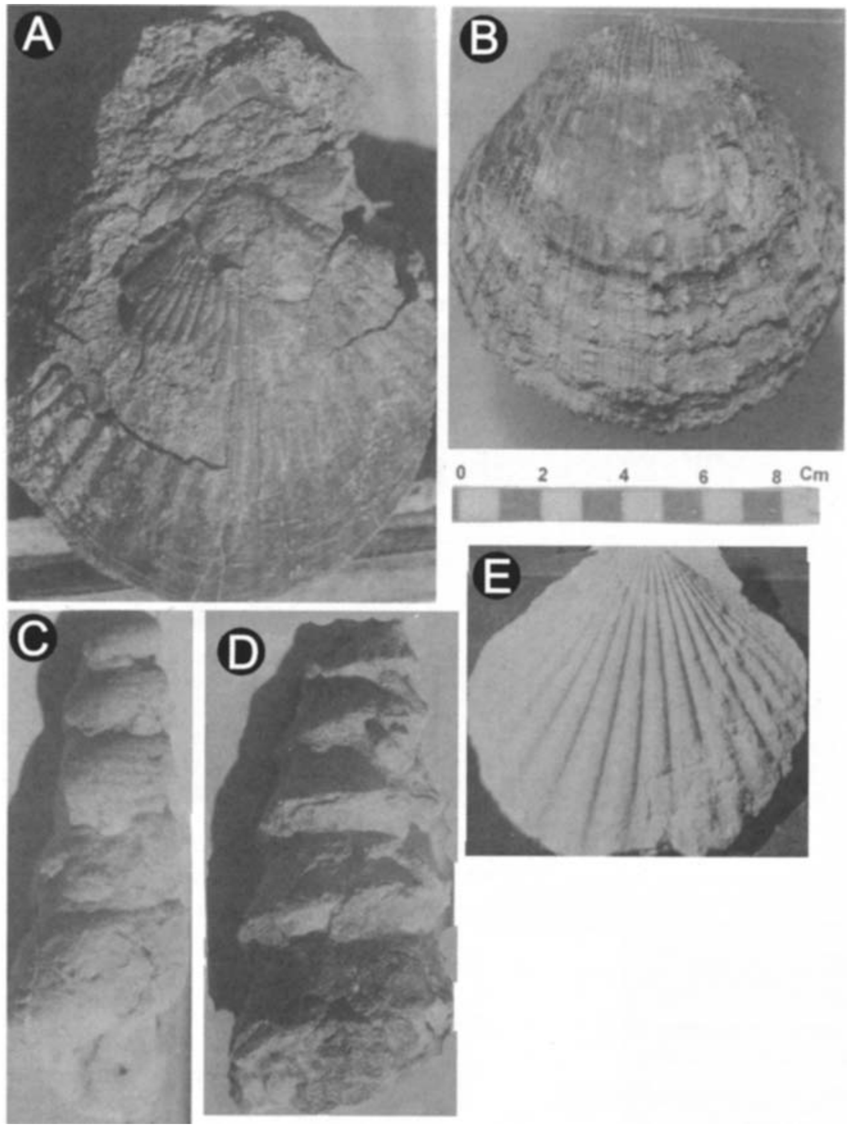


Plate 3. Photographs (A and E) of Chlamys and Pecten, (B) Spondylus, (C and D) Cerithium and Turritella associated mostly with the upper, middle and lower part of the Qom Formation.

Bryozoa are the most commonly occurring skeletal grains. Intergranular secondary blocky crystalline calcite is common. Intragranular voids are filled mostly by micrite or microsparite.

Peloid Bioclastic Packstone to Wackestone

Miliolids, coralline algae, *Rotalia* sp., *Dendritina rangi,* echinoderm and coral fragments are the main skeletal constituents. Peloids and skeletal grains are associated with a micritic to microsparitic matrix.

Miliolid Packstone

Miliolids are the most common grains. Scattered particles of coralline algae and corals are also present within a microsparitic matrix.

The most occurring microfacies are shown in Plate 1.

DESCRIPTION OF THE QOM FORMATION IN THE NAIN AREA

The Qom Formation in the Nain area conformably overlies the Oligocene continental deposits of the Lower Red Formation. It also, underlies the Middle Miocene continental deposits of the Upper Red Formation. In general, the Qom Formation at the study area represents a carbonate-marl depositional system. These cyclic deposits are characterized by intermittent influx of marl and carbonate deposition. The limestones are mostly thin bedded and their average thickness is about 1.0 m. Marl thickness is not uniform and some become sandy. Marl and marly limestone are intermittent and contain foraminifera and larger fossils reflecting the terrigenous influx pattern.

Detailed description of the Qom Formation at Nain is presented in Fig. 3. In the lower most part of the Qom Formation, there are 55 m of sandstone that is red to brown, rippled, cross-bedded, fines upward, and is unsorted and angular. It is followed by lithobioclastic sandstone with reworked sands, bryozoa and mollusk shells and intermittent marl and sandy bioclastic grainstone to packstone. The topmost part of this sequence comprises a thin–bedded sandstone. Bryozoan and mollusk bioclasts and, in minor amount, coralline algae are the most commonly occurring skeletal grains. This facies development reflects a rapid transgression from a continental (Lower Red Formation) to marginal and restricted open marine environment. The thin-bedded sandstone facies occurring at the top of the sequence may indicate deltaic deposition. The sandstone comprises 50-55 % quartz, 20 % altered feldspar, 10-15 % altered mica, 10 % opaque minerals and 1-2 % gluconite.

The next, 117 m of the Qom Formation predominantly consists of marl, alternating with marly limestone, bioclastic packstone to wackestone and wackestone to packstone. Based on fieldwork and microfacies analysis, the limestone and marly layers are widely repeated. Marls are fossiliferous (macrofossils) with Turritella, Cerithium, Spondylus and echinoids. The wackestones to packstones are characterized by smaller foraminifera, bryozoa and gastropod shells. The occurrence of *Archaias* sp., *Peneroplis* sp., and miliolids with gastropods in bioclastic packstone to wackestone indicates low water turbulence in a lagoonal or restricted marine environment of deposition. A decrease in miliolids and an increase in smaller foraminifera and pelagic fauna in the wackestone to packstone in the upper part of the sequence reflects and increase in water depth and the prevalence of an upper shelf open-marine environment.

The next 49 m of marl alternates with bioclastic packstone to wackestone and contains gastropod, bryozoan, echinoid, and coralline algal fragments. Grainstones at the uppermost part of the sequence are characterized by abraded skeletal grains mostly bryozoa and gastropods. This facies relationship reflects a gradual decrease in water depth from a low turbulence, restricted open-marine environment to a higher energy, possibly bar environment of deposition. The upper-most 41 m of the Qom Formation represents an alternating marl and limestone (packstone to wackestone) in the lower part becoming mostly limestone (grainstone to packstone) in the upper part, and finally, and evaporitic marl. Bioclastic packstone to wackestone comprises *Rotalia* sp., mollusk, bryozoan, coralline alga, and echinoid debris. Upward, peloid and miliolid packstone dominates. Finally, grainstone to packstone comprising gastropods, miliolids, echinoids, benthic foraminifera bryozoa, corals and *Dendritina rangi* dominates (Plate 2). The uppermost layer of the Qom Formation is dominated by evaporitic marl. It is overlain by the continental facies of Upper Red Formation. This facies relationship reflects an environment of deposition that gradually changed from open-marine to lagoonal and then to near-shore. In other words, deposition of the uppermost part of the Qom Formation at Nain occurred during a gradual decrease in depth associated with regression.

SEQUENCE STRATIGRAPHY

The concept of sequence stratigraphy brought changes in the analysis of sedimentary basins. The original concept was presented by Sloss (1963), who prosed that interregional unconformities are fundamental for correlating large-scale cratonic sequences. Vail et al. (1977) and Van Wagoner et al. (1988) proposed that depositional sequences are relatively conformable successions bounded by unconformities. Van Wagoner et al. (1988) overviewed the fundamentals of sequence stratigraphy. They recognized that sequences can be subdivided into system tracts. Posamentier and Vail (1988) considered eustatic processes were responsible for the major breaks occurring in depositional sequences. Friedman and Sanders (2000) made specific comments on the relationships between these new ideas and geologic terms in stratigraphy and sequence stratigraphy. They provided historical context on sequence stratigraphy and suggested modifications.

Three depositional sequences were recognized in the Qom Formation (Late Oligocene-Early Miocene?) at north Nain area (Fig 3).

Sequence 1

This is coincident with a 55 m thickness of the lower part of the Qom Formation. It lies conformably on the continental Oligocene Lower Red Formation. The base of the sequence is a brown rippled cross-bedded and fining upward, poorly sorted sandstone parasequence. This marginal prograding stacking pattern (Van Wagoner et al. 1988 and Posamentier and Vail 1988) is characteristic of a lowstand system tracts. The lower sequence boundary is considered to be surface boundary 1 (SB1) (Sarg 1988), because it conformably overlies the continental deposits. Upward, two parasequences of marl and bioclastic limestone indicate the retrograding stacking pattern (Van Wagoner et al. 1988; Posamentier and Vail 1988) of the transgressive system tracts (TST). The upper TST boundary is thought to be the maximum flooding surface (mfs) (Sarg 1988), and corresponds to a bioclastic packstone to wackestone deposited in an open marine environment. A parasequence of bioclastic limestone and marl reflects an aggradational stacking pattern on the upper part of the sequence 1 and corresponds to high stand system tracts.

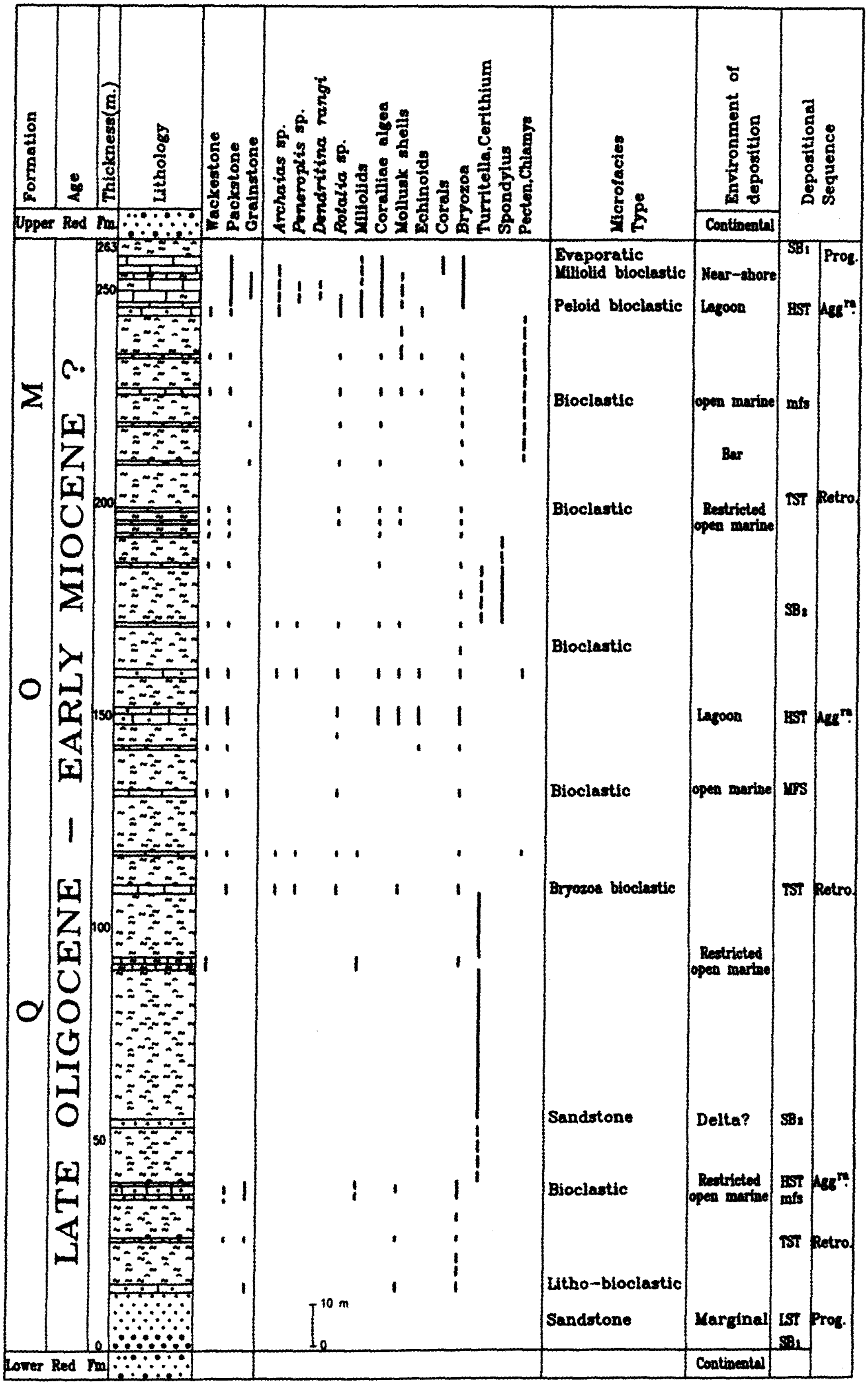


Figure 3. Faunal distribution, lithology, microfacies, depositional environment and depositional sequences of the Qom Formation, North Nain.

The layer deltaic sandstone occurring on the uppermost boundary of the sequence, is considered the upper surface boundary (SB2).

Sequence 2

Parasequences of marl and miliolid bioclastic packstone to wackestone grading into a bryozoa bioclastic packstone to wackestone overlies the high stand succession of sequence 1. These are restricted to an open marine retrograding stacking pattern and are interpreted as transgressive system tracts. The upper part of the sequence is dominated by three parasequences of marl and bioclastic packstone to wackestone. *Rotalia* sp., *Archaias* sp., *Peneroplis* sp., and miliolids are common. This restricted marine aggradational stacking pattern corresponds to highstand system tracts. The upper TST boundary is interpreted as an mfs, where there is a change from deepening (smaller and pelagic foraminifera packstone to wackestone) to shallowing, and open marine to restricted marine or lagoon sediments are deposited.

Sequence 3

The lower part of sequence 3 is characterized by parasequences of marl and bioclastic packstone and wackestone of an open-marine to restricted-marine environment and bryozoa grainstone indicative bar deposits. This interval is interpreted as a retrograde stacking pattern of a transgressive system tracts. Upward, sequence 3 is dominated by marl and calcareous packstone to grainstone and evaporitic marl. Bryozoa and mollusk bioclastic packstone to grainstone typical of open-marine deposits are replaced by peloid and miliolid packstones of lagoon sediments. This interval corresponds to an aggradational stacking pattern of a highstand system tracts. Finally, the uppermost near-shore evaporitic marl underlies by continental deposits of the Upper Red Formation, consisdered as a prograding stacking pattern. The maximum flooding surface corresponds to a change, where open-marine deposits are replaced by lagoon sediments in sequence 3. The upper boundary of the sequence is considered SB1, where it conformably underlies the continental deposits. However, the lower sequence boundary is attributed to SB2 based on its distinctive facies change (Fig. 3).

CONCLUSIONS

During deposition of the Late Oligo-Early Miocene? succession (Qom Formation) along the southern trend of the central Iranian basin three depositional sequences are recognized. Sequence 1 consists of a parasequence of a sandy marginal prograding stacking pattern of the lowstand system tracts. It is followed by parasequences of marl and bioclastic limestone of a retrograding stacking pattern of transgressive system tracts, and then parasequences of bioclastic limestone and marl of an aggradational stacking pattern of highstand system tracts. Sequence 2 consist of parasequences of marl and miliolid bioclastic packstone of a retrograding stacking pattern of the transgressive system tracts. It is followed by bioclastic packstone to wackestone of aggradational stacking pattern of high stand system tracts. Sequence 3 is characterized by parasequences of marl and bioclastic packstone to grainstone of the retrograding stacking pattern of transgressive system tracts. It is then followed by peloid and miliolid packestone of the aggradational stacking pattern of highstand system tracts. Finally, evaporitic marls indicative of the prograding stacking pattern occurs at the top of sequence 3. The lowest and the uppermost boundaries of the succession is considered to be SB1, where, the succession underlies and also overlies by the Upper Red Formation and Lower Red Formation, respectively. Boundaries in between sequence 1 and 2 and between 2 and 3 are considered to be SB2. Maximum flooding surfaces were coincident with facies mostly bioclastic packstone to wackestone deposited in an open-marine environment in which deeper water deposition prevailed.

ACKNOWLEDGEMENTS

Special thanks are due to Dr. Y. Lasemi of Tarbiat Moalem University and Dr. M.N. Gorgij of Zahedan University for their helpful comments. Grateful thanks are extended to Professor G.M. Friedman and *Carbonates and Evaporites* reviewers for thoughtful reviews and constructive comments of this manuscript.

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