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Mansour Ghorbani

Lithostratigraphy of Iran

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Foreword

While working recently with Prof. Mansour Ghorbani in Tehran, in connection with a review project on the biostratigraphy of Iran, I quickly came to appreciate his encyclopaedic knowledge of Iranian geology. I was also greatly impressed by the fact that he had visited so many of the localities that we were discussing. 'The Lithostratigraphy of Iran' is a masterful account that provides an excellent introduction to the stratigraphy of Iran for professional geologists but is written in such a way that it is also suitable for students with an interest in the geology of this region.

With a population of around 80 million and area of 1648 km^2, Iran is a fascinating country spanning the boundary between the Arabian and Eurasian plates. Although it is ranked fourth in the world in terms of proven oil reserves and has a history of hydrocarbon exploration dating back to the drilling of the first exploration well in the Middle East in 1908, relatively little of a summary nature has been published in the English language on its stratigraphy. 'The Lithostratigraphy of Iran' remedies this deficiency by presenting a comprehensive but concise account of the entire stratigraphic succession of the country, region by region. All aspects of the litho- and biostratigraphy of the succession are covered, together with the up-to-date chronostratigraphic interpretation of all of the rock units described. Depositional environments and paleogeographic and tectonic relationships are also discussed in some detail. In addition to the text, the stratigraphy of each geological period is summarized in table form. The descriptions of many of the rock units described are also augmented by clear diagrams and annotated field photographs. Where appropriate, comparisons are made to stratigraphic units in neighbouring countries, but this work deals primarily with Iran.

In Iran, as in most other countries, adherence to the established codes of stratigraphic practice has sometimes been poor in the past, with many formations being inappropriately named and defined, and/or having no clearly designated and described type sections. In other instances, conflicting interpretations of biostratigraphic work have led to confusion concerning correlation and dating. The author has dealt with these issues in a logical and systematic manner, carefully documenting the evidence and discussing how opinions have evolved through time. For example, changes to the postulated age of the Faraghan formation are traced from early suggestions that it was Devonian–Carboniferous, through to the publication of palynological evidence indicating that it is, in fact, Permian, and finally to the acceptance of the latter interpretation by the National Iranian Committee on Stratigraphy. The author's close links with the National Iranian Oil Company have enabled the inclusion of significant amounts of unpublished data on critical subsurface sections that considerably enhance the value of this book.

Professor Ghorbani is to be congratulated on, 'The Lithostratigraphy of Iran', his fifth book that follows 'The Economic Geology of Iran' (Springer, 2013). Few will read this book from cover to cover but that is not its purpose; it is a serious reference book that provides a wealth of up-to-date stratigraphic information on Iran.

Sheffield, UK
March 2018

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Preface

The mountains reared themselves, the streams gushed out,
While from the soil the herbs began to sprout
A farther step-man cometh into sight;
Locks had been made; he was the key of each
By nature first, in order last, art thou;
Hold not thyself then lightly. I have known
Shrewd men speak otherwise, but who shall know
The secrets that pertain to God alone?
Hakim Abu'l Qasem Ferdowsi, 977–1010 A.C.E.
Translated by Warner & Warner, 1905–25

This book is the results of three decades of fieldworks and laboratory works, intended to raise the knowledge of scholars, researchers and students about the geological knowledge of Iran that is one of the goals and missions of the 'Pars Geological Research Center' (Arianzamin). In addition to personal information and available resources, this book is intended to provide a wealth of reports from reputable geological organizations, academic dissertations and reports from companies and organizations related to geology, including the Geological Survey of Iran, National Company Iran Oil, Iran Steel Co. and the Iran Copper Co.

When writing of all parts of the book, I have been consulted by friends with the contents of certain sections. I am very grateful to all of them who encouraged and cooperated me, including Drs. Mehdi Zare, Abdul Rahim Houshmandzadeh, Bahauddin Hamdi, Sayed Ali Aghanabati, Anoshiravan Kani, Mohammad Hossein Motiei, Mozhgan Salehi Yazdi, Azin Ahifer, Asma Aftabi, Masoud Ovissi, Mohsen Ghorbani, Mohammad Ghasemi, Jafar Omrani, Reza Kohansal, Hamid Nazari, Reza Salamati and Jafar Sabouri.

I would like to express my gratitude to Keyvan Zandkarimi, Shahid Beheshti University, who translated the entire book, and as a stratigrapher checked the content and added some recent references and new researches under my authority. Masoud Oveisi is appreciated for editing this book. I am particularly indebted to Prof. Dr. Clayton for his linguistic and stratigraphic edition on the final draft of the book.

Tehran, Iran

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Contents

About the Author

Dr. Mansour Ghorbani was born in Nanaj village, a rural district of Malayer County in the west of Iran on 1961. He completed his primary and secondary educations in his hometown by 1979.

He graduated from high school in 1983. He studied geology at the University of Shahid Beheshti and concurrently Chemistry at Islamic Azad University. He graduated from both courses in 1988 and 1989, respectively. He continued his academic studies in geology at the University of Shahid Beheshti and received his masters (M.Sc.) and Doctor of Philosophy (Ph.D.) degrees in 1993 and 1999, respectively.

Following his academic accomplishments, he joined the geology faculty at the Shahid Beheshti University and has been teaching undergraduates, postgraduates and Ph.D. students till now. He currently holds the associate professor position at the University.

From 1991 to 1996, he was involved in the treatise on the geology at geological survey of Iran. He wrote and compiled a lot of literatures on the geology and mineral deposits, such as economic deposits, soils, iron, antimony, arsenic, mercury, copper, lead and zinc in Iran.

Aside from teaching, he has been working on international and national research projects with mining, oil and gas companies.

The rewards and outcome of these years of studying and working are 38 books, more than 170 academic papers, over 120 scientific and technical reports in reference to natural and mineral resources in Iran and Iranology, as well as the compilation of international metallogeny and gem distribution maps of the Middle East.

He enjoys travelling around the country and abroad; he maintains that while visiting and working in various regions, he meets different ethnic groups with different cultures and traditions in Iran. He has learned how the habitat and the natural surroundings have a greater effect on the people's socio-economic aspects of life in some places than others.

Years of working experiences and personal beliefs in private research work compelled him to establish his own research centre called Pars Geological Research Centre (Arianzamin) in 2002. The staffs at the centre are all dedicated, diligent, experienced and qualified researchers in the fields of geosciences. The centre has performed successfully; it has compiled and published books, literature concerning different aspects of geosciences. The centre has its own website: http://arianzamin.com.

He, from a sociocultural standpoint, endeavours to help countries and people who speak the same language and have had the same or similar cultures, to establish a long-lasting sociocultural bond with one another.

Chapter 1
Precambrian

Being the longest Eon, the Precambrian is divided into the Archean and the Proterozoic which are further divisible into smaller units (Fig. 1.1). Although Archean and lower to middle Proterozoic rocks have not been previously described, Neoproterozoic rocks have been reported in some areas. Formerly, it was thought that Precambrian rocks with ages greater than 1 or even 1.5 Ga. are well developed in Iran. However, recent studies show that the these rocks are of less exposures and are of younger ages spanning the Neoproterozoic and especially Late Neoproterozoic rocks.

Some important outcrops of metamorphic rocks are described, and sedimentary rock units formerly assigned to the late Precambrian (Neoproterozoic)[1] are discussed.

The Neoproterozoic rocks of Iran are divided into three main groups.

(A) Metamorphic rocks and complexes (readers are referred to "The Magmatism and Metamorphism of Iran", Ghorbani 2018)
(B) Sedimentary rock units
(C) Igneous rocks (Ghorbani 2018).

(A) **Metamorphic rocks and complexes**

Some of the metamorphic complexes assigned to the Neoproterozoic are as follows:

The Poshtebadam, Chapdoni, Boneh-shorou and Naibaz complexes; complexes of the Anarak block such as Kaboudan, Chah-Gorbeh; Patyar and Morghab, Lakh marble unit and the Paryar Complex of Central Iran (Valeh and Haghipour 1970; Haghipour and Pelissier 1977; Haghipour 1978).

The Kuh-e sursat, Kheyrabad and Mahneshan Complexes, as well as the Amir Abad Complex of Takab area (Alavi-Naeini 1972).

Metamorphic rocks of Gasht and Shanderman, Talesh mountains (western Alborz) and Gorgan Schist of eastern Alborz have been assigned by recent studies to the Palaeozoic.

[1]Contrary to previous works, we use the term "Neoproterozoic" rather than "late Precambrian".

M. Ghorbani, *Lithostratigraphy of Iran*, Springer Geology,
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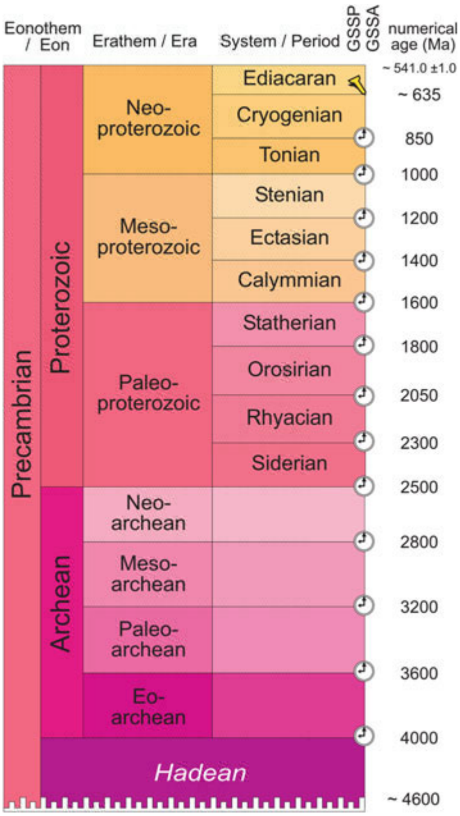
Fig. 1.1 International chronostratigraphic chart of Precambrian (ICS 2015)



It should be mentioned that the grade of metamorphism and absence of fossils lead to the assignment of some highly metamorphosed rocks without any age determination to the Neoproterozoic, for example the Gorgan and Shanderman Schists and the metamorphic rocks of Anarak, Muteh, Samnan, Aligodarz and Azna (Ghorbani 2007).

(B) **Sedimentary rock units of the Neoproterozoic**

The sedimentary rock units of the Neoproterozoic are as follows, although some of these are diachronous, and in some places may be of Neoproterozoic-early Cambrian age.

Alborz: The Kahar, Bayandor, Gharedash and Soltanieh Formations, the latter is definitely diachronous (Neoproterozoic-early Cambrian).

Central Iran: The Tashk I and Tashk II Formations; Kalmard, Morad, Natk, Saghand and Rizu 'Series' of Neoproterozoic Era. However, some evidence indicates the diachroneity of the Desu and Soltanieh formations. Several researchers (e.g. Ahmadzadeh-Heravi 1990) assigned the Hormuz 'Series' to the Neoproterozoic-early Cambrian but there is some evidence that implies that most of the 'Series' is of Neoproterozoic age and does not extend into the Cambrian. However, its upper parts have been published as Cambrian in the stratigraphic logs of NIOC (2016).

Recent paleontological and stratigraphic studies have revised the stratigraphic position of the lithostratigraphic units formerly assigned to the Neoproterozoic (e.g. Bagheri and Stampfli 2008). In the following account, both the traditional and more modern views are presented.

1.1 Neoproterozoic Rocks Based on Recent Studies

The new results show that the Neoproterozoic and lower Cambrian sedimentary facies of Northern Iran differ somewhat from their equivalents in Central Iran. Notably, the Kahar, Soltanieh, Gharedash and Barut formations differ in sedimentary facies from their correlative units, the Tashk Formation, Kushk, Kalmard, Morad, Rizu and Desu 'Series'.

Significantly, some of the metamorphosed rocks and formations were formerly assigned to the Neoproterozoic (Haghipour 1974), while the recent studies show that the protoliths are actually Neoproterozoic in age (e.g. Ghorbani 2013).

It is worth mentioning that metamorphic dating evidence confirms a late Neoproterozoic age for at least some of the units.

1.2 Northern Iran

Amongst the Neoproterozoic rocks of northern Iran, the Kahar, Gharedash, Bayandor and two constituent members of the Soltanieh Fm. (the Lower Dolomite and the Lower Shale) merit discussion. The Neoproterozoic-Cambrian transition coincides with the Middle Dolomite that represents continuous marine sedimentation without any hiatus (Hamdi 1989).

Ghorbani (1999), mainly based on lithological differences, considered the upper part of Bayandor Formation to be equivalent to the upper part of Kahar Formation. Additionally, the Neoproterozoic rocks of the area are metamorphic rocks of the Takab and Mahabad complexes as well as the igneous rocks of the Doran Granite. The results of field observations by the present author imply a Neoproterozoic age for the metamorphic complex in the Takab and Mahabad area, of which the latter is comparable to upper parts of the Kahar formation but with different sedimentary facies.

Kahar Formation

The Kahar Formation is the oldest formation of low metamorphic grade in Northern Iran. Being horizontally and vertically inhomogeneous, the Kahar Formation in the Alborz Mountains is mostly composed of slaty shale, sandy shale, phylite, quartzitic sandstone and, in some localities of carbonates (Dedual 1967). Additionally, in the

Mahabad and Takab regions, it contains some tuffaceous and volcanic beds showing increasing metamorphic grade. Its clastic content increases in its lower part.

In the Takab-Shahin-Dezh and Mahneshan area (1/250,000 geological map of Takab), there are several metamorphic complexes including the Kuh-e-sursat Complex (gneiss, migmatite, mica schist), the Amirabad Complex (schist and amphibolite), the Kheyrabad complex (gneiss, schist, amphibolite and migmatite) and the Mahneshan Complex, all of which have Neoproterozoic igneous-sedimentary protoliths, older than the Kahar Formation (Alavi-Naeini et al. 1976). These complexes have undergone two phases of metamorphism in the late Neoproterozoic and late Triassic.

Soltanieh Formation

As mentioned above, the Soltanieh Formation is a Neoproterozoic-lower Cambrian carbonate formation, the name of which is derived from the town of Soltanieh, Zanjan. Stöcklin et al. (1964) first proposed this name for a thick dolomite unit that forms conspicuous cliffs in the Soltanieh Mountain The presence of shale intercalations has led to subdivision of this formation into three members, namely "Lower Dolomite", "Chapoghlu Shale" and "Upper dolomite".

Previously, the formation was assigned to the Infracambrian due to its relative stratigraphic position and the presence of tube-like organism including forms referable to *Collenia soisser* Fenton and Fenton and *Hadrophycus immanis* Fenton and Fenton. Meyer (1967) correlated these beds to "*Collenia* Limestone Horizon" in the Central Alborz.

Stöcklin et al. (1964) also described *Eoredlichia* sp., Hyolithids, *Wutingaspis* sp. and *Salterella* sp. suggesting an early Cambrian for this formation. Salehi-Siavashani (1980) reported *Biconulites* sp., *Microgastropoda*, *Eoredlichia* sp., Brachiopoda, *Wutingaspis* sp., *Hyolithids* and Trilobites in the limestone intercalation of the Chapoghlu Shale, and suggested an early Cambrian age.

Ashkan (1986) described *Biconulites* sp., brachiopods, echinoid spines, microgastropds and trilobites, and assigned the formation to the early Cambrian.

Hamdi and Golshani (1983), based on the fossils *Hyolithes* sp., ostracods, brachiopoda, *Circotheca*? sp., *Hyolithellus* sp., *Lopochites* sp., *Sachites* sp., and Trilobite fragments proposed an early Cambrian age for Soltanieh Formation.

Later studies by Hamdi (1989) divided this formation into five members, in ascending order; "Lower Dolomite", "Lower Shale", "Middle Dolomite", "Upper Shale" and "Upper Dolomite", of which the lowest two members were assigned to late Precambrian and two highest members to the early Cambrian. The Precambrian-Cambrian transition coincides with the base of the middle Dolomite Member.

The Soltanieh Formation is 864 m thick in its type section but is of variable thickness elsewhere. It was revised by Hamdi (1989) as follows:

(1) **Lower Dolomite**: The Lower Dolomite Member (120 m-thick) is a yellow, well-bedded, recrystallized and cherty dolomite and limestone which, in the Valiabad section, contains thin phosphatic beds yielding phosphatic tubes of *Hyolithellus* sp., while others are resemble *Rugatotheca* sp., fragments of protoconodont *Protohertzina* sp., globomorphs of the *Olivooides multisulcatus* group, and indeter-

minate casts of ?monoplacophorans. In some localities such as the southeastern Soltanieh Mountains and the Hasanakdar section (central Alborz), this unit is thin or absent, so the Lower Shale rests directly upon the Kahar Formation.

(2) **Lower Shale**: the Lower, or Chapoghlu, Shale Member (130–247 m-thick) may intergrade with the underlying dolomite and consists of dark greenish-grey to dark grey shale with gypsum pseudomorphs, dark grey-green sandy shale and calcareous shale in the upper part. Supposedly Vendian acritarchs have been reported from north of Alamut (Seger 1977) while large discoidal algal vesicles assigned to *Chuaria* sp. are generally common. Boudinage structure may also be seen in this part of the succession.

(3) **Middle Dolomite**: the thickness of this member varies between sections. In the Dalir and Soltanieh sections it consists of 144 and 162 m carbonate rocks, respectively. Lower beds at some localities such as the Dalir Section contain grey siliceous limestone interbedded with shale, intergrading to light-color massive calcareous dolomite to dolomite. This member spans the Neoproterozoic-Cambrian boundary. The uppermost 7 m of this unit were assigned to Tommotian Stage (now Stage 2).

The Middle Dolomite Member also comprises approximately 78 m of strata including phosphatic beds and abundant and well-preserved small shelly fossils.

The Dalir section includes tubes of *Hyolithellus vladimirovae* and protoconodonts of the *Protohertzina anabarica* group. Less common elements include tubes of *Anabarites trisulcatus*, *Cambrotubulus decurvatus*, siphogonuchitids, *Palaeosulcachites* sp. and *Siphogonuchites* sp. and globomorphs.

(4) **Upper Shale**: Varying in thickness from place to place, this member is 87 m thick at its type section and 12 m-thick in the Barut section. The lithology of this unit is the same as that of the lower shale member but it tends to be coarser-grained and thicker-bedded in its upper parts. In the upper part of this member calcareous to conglomeratic sandstone grades into dolomitic shale in a transition into the Upper Dolomite Member.

The basal beds consist of a few meters of calcareous shale to black phosphatic limestone, with abundant tubular fossils and molluscs, comparable with those found in the upper part of the dolomite at Dalir but also containing *A.* cf. *tristichus,* hyoliths of the Allathecidae, and a pelagiellid.

The upper part of the Upper Shale Member contains abundant and diverse phosphatized molluscs in the Valiabad Section. Specimens of the *Latouchella korobkovi* group of monoplacophorans, including ‘close-coiled’ *Yangtzespira* sp., ‘lax coiled’ *Bemella* sp., and ‘uncoiled’ *Ceratoconus* sp. and *Obtusoconus* sp., appear c. 20 m from the top of the unit in Valiabad. Other typical elements at this level include *Purella tianzushanemis* and broad monoplacophorans resembling *Protowenella* sp. Pelagiellids of the *Pelagiellalorenzi* group appear in the top 10 m (Hamdi 1995).

(5) **Upper Dolomite Member**: this member is composed of cliff-forming, light grey to light recrystallized massive dolomite that is dark grey to brown weathering in color. The thickness ranges from 405 m in the Soltanieh area to 250–350 m in

the Dalir and Valiabad sections. *Collenia spissa* and *Hadrophycus immanis* are moderately common in the upper part of the member (Meyer 1967). Problematical records of *Salterella* have been reported (Assereto 1963; Stöcklin et al. 1964) but were not confirmed by Hamdi (1989).

In the Sarandon Section of the Central Alborz, this unit is represented by alternations of sandstones and shales. The contact with the overlying formation is transitional and its limit is drawn at the base of the first shale intercalation that initiates the regular shale/carbonate alterations characteristic of the Barut Formation. The Soltanieh Formation underlies the Bayandor Formation and the contact is conformable but marked by a sharp lithological break between purple shale at the top of the Bayandor Fm and the light-colored lower dolomite member of the Soltanieh Formation (Stöcklin and Setudehnia 1991). This member shows more homogeneity than other dolomitic members.

1.3 Central Iran

According to Hamdi (1985) the only Neoproterozoic rocks in Central Iran are the Kushk 'Series', consisting of clastics, acid volcanics, tuffs and carbonates (mainly dolomite).

Differentiation of the Neoproterozoic and Early Cambrian rocks of central Iran presents some difficulties. Other Neoproterozoic-early Cambrian formations include the Morad 'Series', the Rizu volcanic-sedimentary Formation, the Dezu and Tashk formations, the Aghda Limestone, the Kalmard 'Series', the Shorm Beds, and the Anarak metamorphic units.

Samani et al. (1993) established two formations namely the Natak and Saghand formations, considering these to be the oldest sedimentary rock units in Central Iran. Absolute age determinations of 874–750 Ma and 780–583 Ma have been established for the Natak Formation and the Saghand Formation respectively. These units are composed of clastics, sedimentary and volcanic rocks, and overlie the Rizu and Desu 'Series'.

According to the present author, in spite of slightly facies difference, these formations are lateral equivalents of the clastic-volcanic Tashk Formation and lower parts of the Rizu Formation, so the Natk and Saghand formations should not be accepted as new formations.

Field observations by the present author in the Bafgh region suggest a Neoproterozoic age for the volcanic rocks of the Rizu Formation as the overlying Desu Formation is dated as Neoproterozoic-early Cambrian. The Tashk Formation is overlain by Rizu Formation and consists of low-metamorphic clastic sediments, distinguished by their low grade of metamorphism (Fig. 1.2).

In contrast to the Desu and Rizu 'Series', the Tashk Formation tends to have a higher clastic contents and exhibits low regional metamorphic grade which are not seen in the Kushk and Rizu 'Series'. In the Behabab-Gandehdar road section, the

Fig. 1.2 A view of Tashk formation and Kushk 'Series' on the Kushk-Behabad road

Tashk Formation is overlain by the Rizu Fm. so one can conclude that the Tashk Formation is older than Rizu Fm.

Kalmard "Series"

The name of this formation is derived from the caravansary of Kalmard area on the Tabas-Yazd road. It is composed of arkosic sandstone and shale. There is some evidence from extensive outcrops of tuffaceous rocks of low grade greenschist facies metamorphism. These rocks were first described by Gansser (1955) who considered them to Cambro-Silurian in age. Later, Stöcklin (1971) assigned them a Precambrian age and stratigraphically correlated this unit with the Morad, Kahar, and Taknar formations. However, Nabavi (1976) regarded the Kalmard 'Series' as a lateral equivalent of the Heshem Formation and assigned it to the early Cambrian. Among other researchers who worked on the formation, Aghanabati (1975) considered a Neoproterozoic age based on relative stratigraphic position. Since rocks similar to the dolomites of Soltanieh overlie this succession in Tabas, the views of Stöcklin et al. (1964) and Aghanabati (2008) are correct.

It seems that Kalmard 'Series' is the equivalent to the Neoproterozoic Upper Tashk Member in the Behabad area. Because the rocks being equivalent to the Rizu 'Series' does not show any evidence of metamorphism. Hence because of the same lithology and grade of metamorphism, it is better to consider the Kalmard 'Series' to be equivalent to the Upper Tashk Member. However, the Kalmard 'Series' rocks exhibit greenschist facies regional metamorphism. From the above evidence, the Kalmard 'Series' is older than Rizu 'Series' and is considered equivalent to the Kahar Formation of Alborz and Tashk Formation of the Bafgh-Saghand area.

To show more details of Neoproterozoic-lower Cambrian rocks of Central Iran, a review of the Huckriede et al. (1962), Stöcklin (1971, 1986) as well as Hamdi and Zhion (1992) is presented in the following account.

Morad and Rizu 'Series'

Huckriede et al. (1962) established the name, "Morad 'Series'"[2] for a succession (more than 500 m-thick) of uniform clastic sediments including silty shale and sandy shale, fine-grained sandstone, arkosic mica-bearing sandstone and quartzite sandstone in the Abmorad, northern Kerman and northern Zarand (Rodshuro and Gogdel Mine area). The same authors, also described the Rizu 'Series' to include a Lower Cambrian succession of dolomite beds, sandstone, sandy and dolomitic shale, conglomerate as well as basic and acidic volcanic rocks.

According to Huckriede et al. (1962) the sediments of the Morad 'Series' were formed during the Neoproterozoic, and were affected by the Asiatic orogenic phase. The basal conglomerate of the Rizu 'Series' overlies the Morad 'Series' with an angular unconformity in the Abmorad area. However, in the Gogdel area, the Rizu Formation is overlain by the Desu 'Series' consisting of sandstones, evaporites and carbonate sediments together with acidic volcanic rocks.

Stöcklin (1971, 1986) correlated the Morad 'Series' with Kahar Formation, subsequently confirmed by field observations by the present author. He considered the Rizu and Desu 'series' as complex rather than 'Series', and finally correlated them with Soltanieh Formation of the Northern Iran. He, also, presumed that the Kushk 'Series' that contained Neoproterozoic Ediacaran fossils was a part of Rizu 'Series'. However, Hamdi and Zhion (1992) rejected the concept of the Morad and Rizu 'Series' of Huckriede et al. (1962) in the Kuhbanan area, northwestern Zarand, and instead considered it to be the lateral equivalent of the Heshem and Aghda formations. Additionally, the transition of the Heshem Formation to the Aghda Formation is continuous. The latter formation having been attributed by Hushmandzadeh et al. (1988) to the Cambrian.

An exactly similar sequence can be found at the Kushk mine to the west of Kharneghan Village. In this area, more than 200 m of shale of the Heshem Formation pass gradually into fetid, black limestone of Aghda Formation.

Consequently, the Cambrian Heshem and Aghda formations are underlain the Rizu 'Series', so the latter formation is certainly Neoproterozoic in age. The sequence at Kushk mine starts with shale, mineral-bearing unit of the Kushk 'Series', and is overlain by 200 m of tuffs and dolomites of the Rizu 'Series'. The latter unit is overlain by the Cambrian Heshem and Aghda formations, confirming the Neoproterozoic age of the Rizu 'Series'.

Shorm Beds

Ruttner et al. (1968) described a sequence exposed between Cheshmeh-e Shorm and Cheshmeh-e Kharmayu in the Derenjal Mountains, Shirgesht area. This consists of a

[2]Field observations by the present author in the Kushk Mine, Bafgh area, imply that it is better to rank the series as formation because the underlying (Kushk series) and overlaying (Heshem Formation) strata are well exposed.

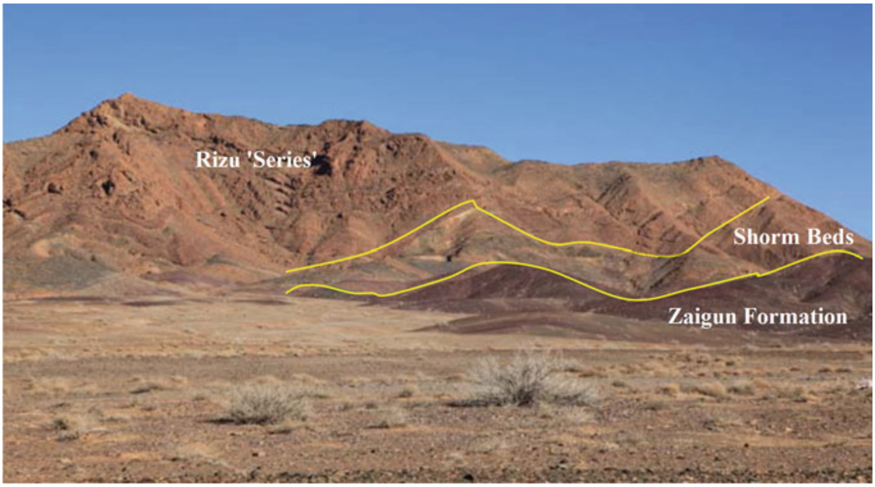


Fig. 1.3 A view of the Neoproterozoic-lower Cambrian rocks of Derenjal mountain

slightly metamorphosed complex of slaty limestone, calcite-vein shale, green slate, red phyllitic shale and siliceous dolomite assigned by them to Neoproterozoic. The same authors believed that these strata are the oldest rocks of the Shirgesht area and that they overlie rocks equivalent to Soltanieh with a paraconformity (Fig. 1.3).

In contrast, later studies by Hamdi (1995) implied an early Paleozoic age for the Shorm Beds and considered these to be the lateral equivalent of the Barut Formation.

Taknar Formation

Razzagh Manesh (1968) described a succession of slightly metamorphosed tuffaceous green schist with alternations of meta-rhyodacite and meta-rhyolites, exposed around the Taknar mine in the Kashmar area in northeastern Iran. This author assigned a Neoproterozoic age to the Taknar Formation that is disconformably overlain by the Paleozoic sediments.

Stöcklin (1972) and Müller and Walter (1983) both changed "Taknar Formation" to "Taknar 'Series'" and chronostratigraphically correlated this with the Neoproterozoic Kahar Formation.

However, Hamdi (1995) rejected their Neoproterozoic age assignment and attributed the Taknar Formation to the early–late Cambrian based on palynomorph and algae.

On the basis of regional field observations, Ghorbani (1999) correlated the Taknar 'Series' with the Ordovician Shanderman and Gorgan Schist. However, this relationship was disproved by further field observations by the same author that revealed that the supposed Ordovician strata in the Kashmar area are actually Cambro-Ordovician in age and are non-metamorphosed correlatives of the Shirgesht Formation. Hence, a Neoproterozoic age is correct.

Metamorphic rocks of the Muteh area

There are different opinions about these rocks. Thiele et al. (1968) ascribed them to the Neoproterozoic; an interpretation rejected by the later studies of Rashid-Nezhad (2002) based on the presence of early Paleozoic palynomorphs.

1.4 Zagros

Hormuz 'Series'

The description of the salts of Hormuz (Tavernier 1642) is one of the earliest recorded geological observations made in Iran. Blandford (1872) first introduced the name, Hormuz Salt Formation for the complex of salt and associated sedimentary and igneous rocks. Pilgrim (1908) changed the name, "Hormuz Formation" to "Hormuz 'Series'" comprising halite, gypsum, and blocks and contorted masses of many sizes and compositions, including black laminated fetid limestone, brown cherty dolomite, and red sandstone, and also igneous material (Figs. 1.4 and 1.5). He divided this 'Series' into four units as follows:

1. Purple coarse-grained sandstone
2. Volcanic rocks including tuff, agglomerate and gypsum
3. Dolomite, limestone, shale and rhyolite
4. Salt.

Stöcklin (1986) used the name "Hormuz Complex" and correlated this unit with the Bayandor, Soltanieh, Barut, Zaigun and Lalun formations, as well as the lower-most member of Mila Formation and the Punjab Saline 'Series' of the Salt Range.

Fig. 1.4 A view of the Hormuz 'Series'

Fig. 1.5 A view of rhyolites of the Hormuz 'Series'

Ahmadzadeh-Heravi (1990) despite the absence of the stratigraphic order renamed the "Hormuz 'Series'" the "Hormuz Formation" and divided it into 4 units; H1, H2, H3 and H4. These authors believed that, despite the lithological differences between domes, the overall lithological succession is similar. They also presented another description of the Hormuz Formation as follows:

H1 Unit, salt unit of Hormuz Formation

The base of this unit is not exposed in the studied sections. This unit is mainly composed of salt interbedded with thin-bedded tuffs, marls, laminated limestone and iron oxide and sulfide. It should be mentioned that the observed lineation is actually related to the dynamic and thermodynamic metamorphic structures, and so should be referred to as foliation.

One can conclude that this unit was derived from clastic sediments, based on the presence of fine- to coarse-grained carbonate and volcanic clasts. Nevertheless, the dominant brittle tectonism affecting the diapirs, has resulted in this feature. The H1 Unit is continuous with the H2 Unit Ahmadzadeh-Heravi (1990).

H2 Unit, red soil unit

This unit is mainly composed of red ochre rocks and is simply recognized by this feature. It is a succession of white to yellow marl, anhydrite deformed gradually to the gypsum, tuff, ignimbrite, black thin-bedded limestones as well as laminates of iron hydroxide and oxides. The composition of the ignimbrite is mainly rhyolite and dacite of alkalic origin. Because of the amalgamation during formation, these rocks include salts and gypsum observed in both thin section and hand samples. In some areas, there are a few beds of red ripple marked sandstone and fine-grained white tuff contaminated with salts and gypsum. The thickness of the unit differs from place to place.

H3 unit, black algal limestone

Fetid, black, thin-bedded limestone with algal fossil remnants are assigned to the Neoproterozoic-Cambrian, based on the presence of echinoderm and stromatolite remains. Its thickness may reach 50 m.

H4 Unit, clastic-volcanic unit

The lithology of this unit is specific to the diapirs of the area, and is observed where the H1 unit does not crop out or is thin. There is extensive outcrop of the unit in the salt diapirs of Hamiran, Lamzan and Pozeh, with thicknesses exceeding 500 m.

The lithology of this unit is mainly red and green ripple-marked sandstones alternating with green tuffite. In some domes, it appears as fine-grained tuffite due to the abundance of volcanic rocks. This is the main reason for the volcanic appearance of the rocks alternating with the clastic sediments. It also appears as volcanic units alternating with clastic beds. Moreover, the upper part of the unit contains some anhydrite layers interbedded with black limestone. Tuffitic beds appear in the lower part of the unit amalgamated with salts and anhydrite, and in rock samples with kaolinite.

The Hormuz 'Series' is divided into two sequences of salt (1–2.5 km thick) separated by a few hundred meters of carbonates and red beds. The lithofacies boundaries of both these sequences occur above old faults in the Precambrian basement (Talbot and Alavi 1996).

The age of this 'Series' has long been disputed and different ages have been suggested. Pilgrim (1922) first regarded the Hormuz rocks to be post-Cretaceous in age, but he later (1924) assigned the salts to the Triassic and other rocks to Jurassic. Richardson (1926) suggested a post-Cretaceous age. Following the discovery of Cambrian trilobite, a Cambrian age was suggested (Lees 1927), verified by later researchers (e.g. Ahmadzadeh-Heravi 1990; Hamdi 1995). However, regional comparison with central Iran and neighboring countries confirmed the Neoproterozoic-Cambrian age of the Hormuz 'Series'.

The magmatism and tectonic events of the Neoproterozoic-Cambrian Pan-African orogeny was contemporaneous with the formation of the 'Hormuz 'Series'' (Sillitoe 1980). During this time, due to crustal extension, several intra-continental rifts were created along the northern part of the Gondwana Supercontinent, leading to alkaline magmatism involving a wide range of ultra-basic to acidic types that were eventually mixed with clastic, shallow and salt deposits (Sillitoe 1980; Berberian and King 1981; Samani 1988; Ghorbani 2007). The Neoproterozoic-Cambrian strata of well outcropped sections are summarized in Fig. 1.6.

The author is of the opinion that, in view of its stratigraphic position as well as the magmatic record of Iran, the Hormuz 'Series' must be of late Neoproterozoic age.

Figure 1.7 is a schematic illustration of the Neoproterozoic-Cambrian lithostratigraphy of the main regions of Iran. Table 1.1 also summarizes the general features of the Neoproterozoic-Cambrian rocks of Iran. The field images of selected Neoproterozoic sections are depicted in Figs. 1.8 and 1.9.

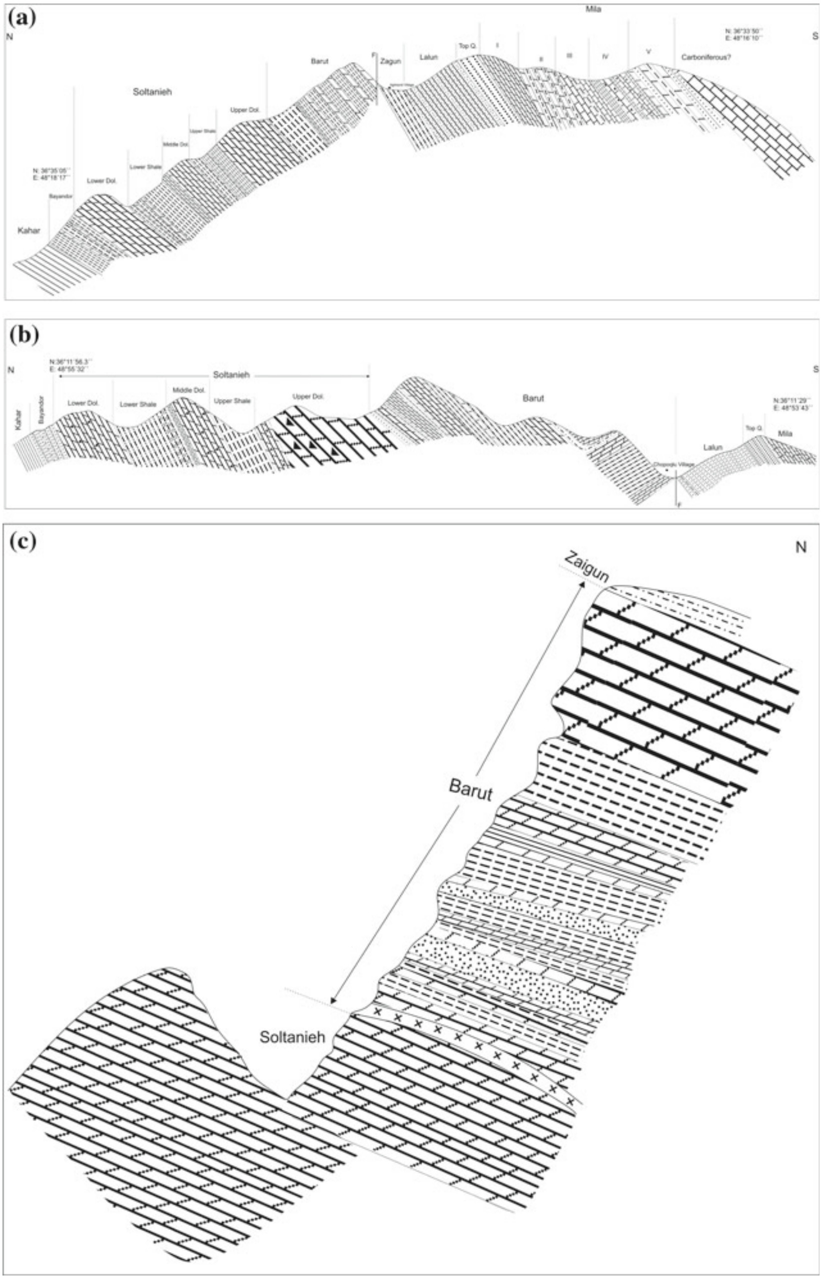


Fig. 1.6 **a** Stratigraphic section of southern Zanjan, around Barout-Aghaji Village. **b** Stratigraphic section of Neoproterozoic-lower Cambrian rocks around Chapoghlou Village, southern Abhar. **c** Barut and Soltanieh Formations of the Deh-molah section at the western Shahroud. **d** Stratigraphic section through the Soltanieh Formation at Valiabad area. **e** Paleozoic rocks in the Kushk stratigraphic section. **f** Paleozoic rocks in the Ghali-Kuh section

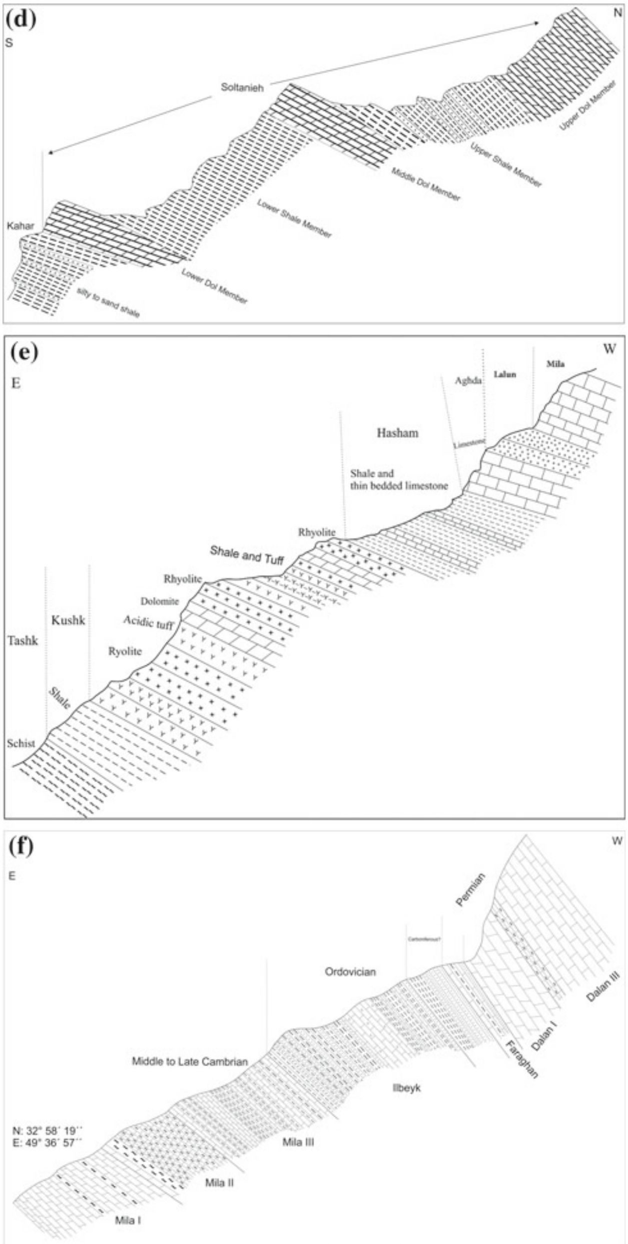


Fig. 1.6 (continued)

Fig. 1.7 Lithostratigraphic column of the Neoproterozoic-Lower Cambrian rocks of Iran

Table 1.1 Lithostratigraphic features of Neoproterozoic-lower Cambrian rock units of Iran

Rock unit	Chronostratigraphy	Lower/upper Boundary	Lithology and thickness at type section	Notes (references, comments)
Neoproterozoic (Alborz-Azarbaijan)				
Kahar Fm.	Neoproterozoic	Lb[a]. does not outcrop anywhere. Ub. Bayandor or Soltanieh formations and in some localities, the Ghare-Dash Rhyolite.	Silty shale, sandy shale, quartzitic sandstone, dolomite and limestone in the lower part; Sandstone and quartzitic sandstone in the upper part; Thickness: 1600 m	Hamdi (1985, p. 34), Aghanabati (1998, p. 52), Alavi-Naeini (2009, p. 50) The formation is metamorphosed (slate and phylite; greenschist facies). The Kahar Fm. was considered to be the oldest sedimentary unit of Alborz and Azarbaijan
Bayandor Fm.	Neoproterozoic	Lb. of the type section is the Doran Granite but in other areas it is underlain by the Kahar Formation. In some places such as Shahin-Dezh, the boundary is continuous Ub. is continuous and conformable with Soltanieh Fm.	Purple sandstone, mica-bearing silty shale interbedded with stromatolite bearing brown dolomite. Reported thickness: 498 m but the actual thickness is much less (ca.100 m).	Hamdi (1985, p. 21), Ghavidel–Syooki (1985, p.), Aghanabati (2004, p. 116), Aghanabati (2008, p. 144), Alavi-Naeini (2009, p. 65), Article: Ghavidel-Syooki (1995)
Gharedash Fm.	Neoproterozoic	Lb. Kahar Formation Ub. disconformable or interfingering with Bayandor Fm.	Alkali ryolithic lava, acidic tuff observable in northwestern Iran, Azarbaijan, Takab and Mahabad. Extrusive equivalent of the Doran Granite Thickness: 1140 m	Book: Aghanabati (2004), Aghanabati (2008, p. 40), Alavi-Naeini (2009, p. 64)

(continued)

Table 1.1 (continued)

Rock unit	Chronostratigraphy	Lower/upper Boundary	Lithology and thickness at type section	Notes (references, comments)
Soltanieh Fm.	Neoproterozoic-early Cambrian	Lb. Bayandor and Kahar Formations Ub. discontinuous or continuous with Barut Formation	Hamdi divided the formation into five members in ascending stratigraphic order, as follows: 1. Lower Dolomite: cherty dolomite and calcareous dolomite 2. Lower Shale: silty shale, slaty sandy shale interbedding with stratified silica-bearing limestone and calcareous shale 3. Middle Dolomite: silica-bearing limestone interbedding with shale. 4. Upper shale: lithology same as Lower Shale but tends to be coarser grained and thicker bedding. 5. Upper Dolomite: cliff-forming dolomite Thickness:1160 m	Book: Alavi-Naeini (1993, p. 50), Hamdi (1995, p. 47), Aghanabati (2008, p. 157), Alavi-Naeini (2009, p. 68) Thesis: Thiab-Ghodsi (2007), Shabestari (1994), Ashkan (1986) Article: Hamdi and Zhion (1992) Research project: Lasemi (1994) In places where the Bayandor Fm. is not exposed, the Soltanieh Fm. overlies the Kahar Fm.
Neoproterozoic (Central and Eastern Iran and Sanandaj-Sirjan)				
Morad 'Series'	Neoproterozoic	Lb. does not exposed Ub. disconformable with Rizu 'Series'	Silty shale, sandy shale to sandstone, arkosic sandstone and quartzitic sandstone Thickness: more than 500 m	Hamdi (1995, p. 24), Aghanabati (2008. P. 81), Alavi-Naeini (2009, p. 56) The Morad 'Series' mainly outcropped in the Abmorad, northwestern Kerman and northern Zarand; and considered as the equivalent of Upper Tashk Member

(continued)