

## **Surdud Group, a New Lithostratigraphic Unit of Jurassic Age in the Yemen Arab Republic**

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**Abstract.** The Surdud Group is introduced as a new lithostratigraphic unit to accommodate the Amran Formation and the transitional beds lying between the Amran and Tawilah Formations in the Yemen Arab Republic. The Amran Formation consists of fossiliferous limestones with thin marl, shale and siltstone interbeds, and on the basis of its fossil content and stratigraphical position it is assigned to the Middle-Late Jurassic (Bajocian-early Kimmeridgian). The transitional beds are represented by evaporites and marly clastics. The evaporites are restricted to the eastern regions and are included in the Sabatain Formation. The marly clastics which are included in the Madbi Formation, are distributed in the rest of the country. The Sabatain and Madbi Formations are laterally equivalent and on the basis of their fossil content and stratigraphical position they are assigned to the Late Jurassic (late Kimmeridgian). The Sabatain Formation is subdivided into four members which are from base to top: the Shabwa Salt, Layadim Shale, 'Ayad Gypsum and M'qah Sandstone Members. The last two members are laterally equivalent and intertonguing in some localities. The Sabatain Formation is correlated with the Hith and Gotnia Anhydrites of Arabia and Iraq, respectively, which indicates that at the end of the Jurassic evaporitic conditions were widespread in this area. The age assignment of this formation and its equivalents (the Hith and Gotnia) is substantiated in the present study where numerous fossil fish have been recorded.

### **Introduction**

In the Yemen Arab Republic, the Mesozoic Era is represented by a thick sequence of sedimentary rocks which consist of two continental clastic units separated by marine unit. These three units were included in the Kohlan, Amran and Tawilah "Series" [1]. The Kohlan and Tawilah "Series" were studied by El-Nakhal [2,3] and, therefore, they will not be discussed in the present study.

Between the Amran and Tawilah “Series” there is a marly clastic and evaporitic sequence which constitutes a transitional zone between the Amran Limestone and the overlying Tawilah Sandstone. Originally, the transitional beds were included in the “Tawilah Series” [1]. Beydoun [4,5], however, correlated them with the Sabatain Formation of the People’s Democratic Republic of Yemen. In his study of the “Tawilah Series”, El-Nakhal [3] gave the Tawilah sequence a formational rank, revised its original definition, removed the transitional beds from its base and attached them to the top of the Amran Limestone. He also suggested that the “Amran Series” and the transitional beds be treated as two distinct formations which should be combined together in one group.

Following these suggestions, the transitional beds are given formational rank here, and on lithic grounds, they are correlated with and named after the Sabatain and its laterally equivalent Madbi Formation of the People’s Democratic Republic of Yemen as the Sabatain-Madbi Formations. Furthermore, the Surdud Group is introduced here as a new rock unit to accommodate the Amran, Sabatain-Madbi Formations in the Yemen Arab Republic to express their natural relationship and to facilitate their mapping.

The present study aims to discuss the stratigraphy of the Surdud Group and its constituent subdivisions.

## **Surdud Group**

### **Definition**

The Surdud Group is introduced as a new rock unit to include the Amran, Sabatain and Madbi Formations which consist of limestone, marl, shale, siltstone, sandstone and evaporites (gypsum and rock salt) of Middle-Late Jurassic age lying between the Kohlan Group (Permian-Early Jurassic) below, and the Tawilah Formation (Cretaceous-Paleocene) above [2,3].

### **Type locality**

The type locality of this group is taken at the northern side of Wadi Surdud near its junction with Wadi Al-Ahjar. Wadi surdud lies about 52 km west-southwest of Sana’a and extends westwards to the Red Sea (Fig. 1).

Approx. lat. (of the type locality) 15° 16' N

Approx. long. (of the type locality) 43° 42' E

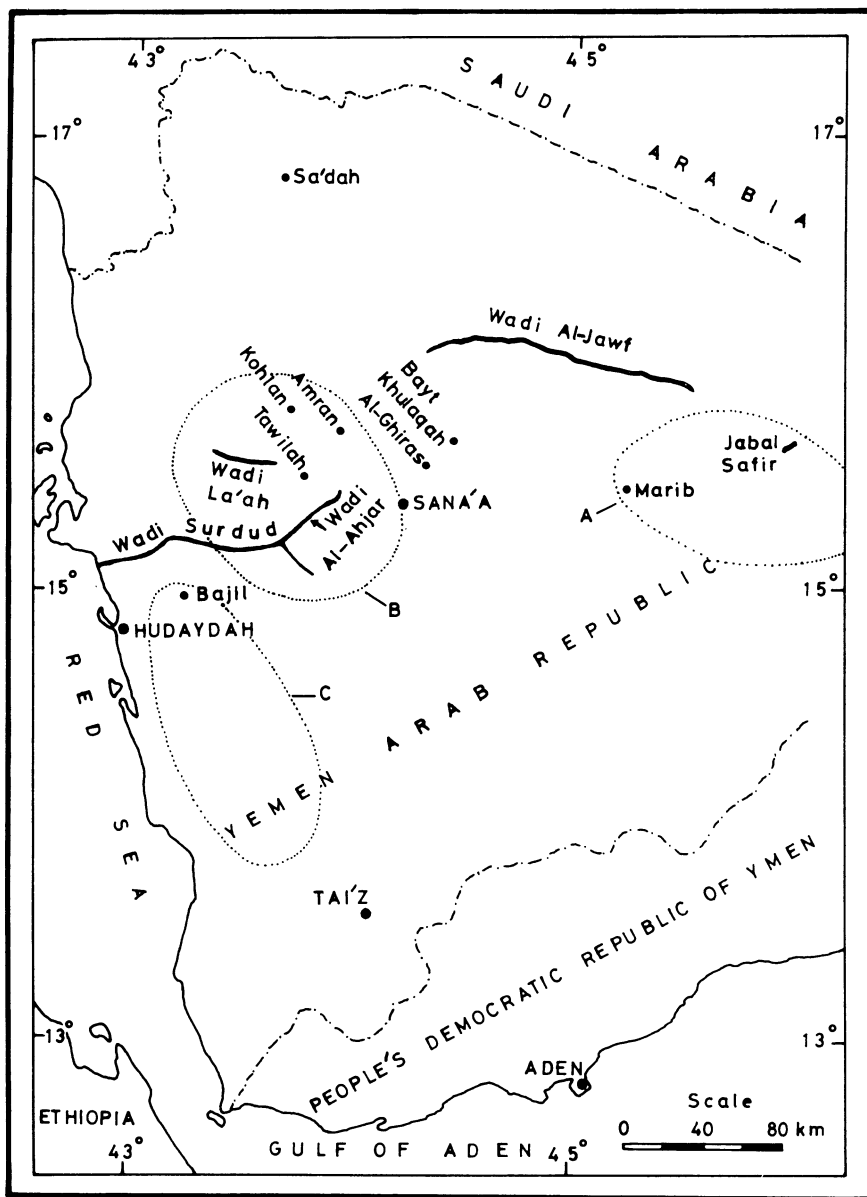


Fig. 1. Yemen Arab Republic, index map showing localities cited in the text and the approximate boundaries of the Middle-Late Jurassic sedimentary basins, A: Ramlat as Sabatain Basin, B: Jabal Maswar Wadi La'ah Basin, C: West of the Al-Aridah Basin.

**Thickness** About 360 m.

### **Lithology**

In the type locality, the lower 300 m of the Surdud Group consist of pure and shaly limestones (= Amran Formation), overlain by 60 m of light green and light yellow shale and some sandy beds that enclose alternating layers of black shale and marl (= Madbi Formation).

### **Contacts**

In the type area which lies in the centre of one of the Jurassic sedimentary basins, namely, the Jabal Maswar-Wadi La'ah basin (Fig. 1), both the lower and upper contacts with the Kohlan Group and the Tawilah Formation, respectively, are gradational and conformable. However, in regions other than the type locality, one or both contacts may be unconformable especially in areas lying near the margins of the sedimentary basins.

### **Fossils**

Numerous fossils have been recorded in the Surdud Group. These include corals, brachiopods, molluscs, echinoids, crinoids, foraminifers, ostracods, fish, trace fossils, spores, pollen grains and plant remains (see details under individual formations).

### **Age**

On the basis of its fossil content and stratigraphical position, the present group is assigned to the Middle-Late Jurassic (Bajocian – Kimmeridgian).

### **Distribution**

The Surdud Group is exposed over wide regions of the Yemen Arab Republic. Geukens [6] subdivided the exposures of this rock unit on the basis of their facies characteristics into four areas which are:

- a – South Bajil-Sana'a.
- b – Wadi surdud and Wadi La'ah.
- c – Amran-Sa'dah-Al-Jawf.
- d – Marib-Safir.

### **Remarks**

In the type area, the group sequence is well exposed, well developed and sedimentation seems to be continuous from the Early Jurassic to the Paleocene. The constituent formations of the Surdud Group were deposited during the same marine sedimentary cycle and therefore, they are combined together to express their natural relationship.

### Subdivisions

In the People's Democratic Republic of Yemen, the equivalents of Surdud Group were included in Amran Group which was subdivided by Beydoun [4,5] as follows:

<b>In the salt-domes area</b>	<b>In the coastal area</b>
Naifa Formation	Naifa Formation
Sabatain Formation	Madbi Formation
'Ayad / M'qah Members	
Layadim Member	
Shabwa Member	
Shuqra Formation (?), unexposed	Shuqra Formation

These subdivisions are also recognized in the Yemen Arab Republic, but the Naifa Formation is not represented, and the equivalents of Shuqra Formation are assigned to Amran Formation. Consequently, it is suggested to subdivide Surdud Group in the Yemen Arab Republic as follows:

<b>In the eastern regions</b>	<b>In the remaining regions</b>
Sabatain Formation	Madbi Formation
Ayad / M'qah Members	
Layadim Member	
Shabwa Member	
Amran Formation	Amran Formation

The suggested subdivision of Surdud Group is summarized and correlated with earlier nomenclature in Table 1. A detailed lithostratigraphic description of each of these units is given below from base to top.

### Amran Formation

#### Definition

The name Amran was originally introduced by Lamare et al. [1] as "Amran Series" to include the Jurassic calcareous sequence overlying the "Kohlan Series" and underlying the transitional beds in Yemen. The original definition of this rock unit is followed in the present study and as its sequence is not divisible into mappable smaller units, it is given formational rank. Accordingly, the Amran is a formation which includes the calcareous sequence consisting mainly of limestones with thin shale and clay interbeds of Middle-Late Jurassic age lying between the Affar Formation (Early Jurassic) below, and the Madbi/Sabatain Formations (Late Jurassic) above.



### Type section and locality

The type section of the Amran Limestone was not precisely located by Lamare *et al.* [1], but Geukens [6] deduced that its type locality lies in the southern side of Wadi La'ah (Fig. 1). El-Anbaawy [7] erroneously mentioned that the type locality of the Amran Formation lies near Amran Town.

### Thickness

The thickness is variable from place to place in relation to local subsidence [6]. In the type area (Wadi La'ah), its thickness is about 320 m [1].

### Lithology

The Amran Formation is characterized by its calcareous facies. In the type locality it consists of light gray limestone with shale and marl interbeds. In Bajil area, it begins with a few meters of basal conglomerate followed upwards by blue and dark gray limestones and shales. In Amran, Sa'dah and Al-Jawf areas, as well as in Marib-Safir area, this formation consists of light yellow limestone.

### Fossils

The Amran Limestone has yielded a rich assemblage of fossils including corals, echinoderms, molluscs, brachiopods, ostracods, foraminifers, trace fossils, spores, pollen grains and plant remains. El-Anbaawy [7] erroneously referred to the occurrence of planktonic foraminifera in the Amran sequence. However, all the foraminifers recorded in the present study in the Amran Limestone are exclusively benthic and they are shown in Table 2. In addition to these forms, the following fossils are recorded: ostracods, *Pseudocidaris* sp., *Nerinea* sp., *Rhynchonella* sp., *Ostrea* sp., gastropods, bivalves, ammonites, irregular echinoids, echinoid spines, crinoids, and very large trace fossils in the form of branching burrows belonging to the genus *Thalassinoides* Ehrenberg, sclerites of the holothuroid species *Theella sinaiensis* Said and Barakat, (Bajocian-Bathonian), and gyrogonites of the charophyte species *Porochara fusca* Mädlar, (Kimmeridgian). Fossils recorded by previous workers [6,8,9] include the following forms:

**Foraminifera:** *Haplophragmium coprolithiforme sequanum* (Mohler).

**Coelenterates:** *Comophyllia thamnastroides* Gregory, *Plesiophylumm* (= *Oppelismilia*) *harensis* Basse, *Synastraea* sp. cf. *S. concinna* Goldfuss.

**Brachiopods:** *Burmihynchia* ? sp., *Daghanirynchia* ? sp., *Rhynchonella moravica* Uhlig, *R.* sp., *Somalirynchia africana* Weir, *S. africana* var. *mesoloba* Muir-Wood, *S.* sp., *Terebratulula aualites* Stefanini, *T.* sp. cf. *T. bicanaliculata* Schlothheim, *T. subsella* Leymerie, *T. suprajurensis* (Thurmanni). *T.* sp.

**Table 2. Benthic foraminiferids recorded in the present study in the Amran Formation, and their stratigraphical ranges.**

Foraminiferal species	Stratigraphical range
<i>Ammobaculites glaessneri</i> Said and Barakat <i>A. magharaensis</i> Said and Barakat <i>Eoguttulina inovroclaviensis</i> (Bielecka and Pozaryski <i>Kurnobia morrisi</i> Redmond <i>Nodosaria nitidana</i> (Brand) <i>Spirillina infima</i> (Strickland)	Kimmeridgian
<i>Ammobaculites hagni</i> Bhalla and Abbas <i>A. reophacoides</i> Bartenstein	Oxfordian
<i>Haplophragmoides qattaraensis</i> Hassan, Hassanein and Abd El-Shafy <i>Kurnobia bramkampfi</i> Redmond <i>K. jurassica</i> (Henson) <i>Pseudomarssonella media</i> Remond <i>Riyadhella intermedia</i> Redmond	Callovian
<i>Pseudomarssonella maxima</i> Redmond <i>Riyadhella hemeri</i> Redmond <i>Kurnobia variabilis</i> Redmond	Bathonian or Callovian
<i>Pseudomarssonella bipartita</i> Redmond <i>P. inflata</i> Remond <i>P. mucclurei</i> Redmond <i>P. reflexa</i> Redmond <i>Riyadhella arabica</i> Redmond <i>R. nana</i> Redmond <i>Rotundata</i> Redmond	Bathonian
<i>Lenticulina quenstedti</i> Guembel) <i>L. varians</i> (Bornemann) <i>Marginulina simplex</i> (Terquem) <i>Spirillina polygyrata</i> Guembel	Bajocian – Kimmeridgian
<i>Lenticulina subalata</i> (Reuss)	Bajocian – Oxfordian
<i>Ammobaculites fontinensis</i> (Terquem)	Bajocian – Callovian
<i>Pseudomarssonella primitiva</i> Redmond	Bathonian and possible late Bajocian
<i>Riyadhella elongata</i> Redmond	Bajocian – Bathonian

**Bivalves:** *Alectryonia pulligera* Goldfuss, *Anatina* (= *Cercomya*) *striata* d'Orbigny, *A.* (= *C.*) sp., *Arca sublata* d'Orbigny, *Avicula* sp. cf. *A. gessneri* Thurmann and Etallon, *Brachidontes* (*Arcomytilus*) *laitmairensis* (de Loriol), *Camptonectes* sp. aff. *C. viridunensis* (Buvignier), *Cardium banneanum* Etallon, *C.* sp., *Ceratomya* sp. cf. *C. plicata* Agassiz, *C.* sp. cf. *C. wimmisensis* (Gillieron), *Ceratomyopsis* sp. cf. *C. kiliani* (Rollier), *Chlamys* (*Chlamys*) *curvivarians* Dietrich, *C.* (*C.*) sp., *Eligmus* sp. cf. *E. aualites* (Stefanini), *E.* sp. cf. *E. rollandi* Douville, *Exogyra africana* Lamarck, *E. bruntrutana* Thurmann, *E. fourtaui* Stefanini, *E. nana* (Sowerby), *E.* sp., *Gryphaea balli* (Stefanini), *Homomya inornata* (Sowerby), *Inoperna perplicata* (Etallon), *Isocardia* (= *Ceromya*) *striata* d'Orbigny, *Lima* (*Plagiostoma*) *harronis* Dacque, *L.* (*P.*) sp., *Lopha karrenbergi* Basse, *L. solitaria* (Sowerby), *Lucina substriata* Roemer, *Mactromya aequalis* Agassiz, *M.* sp., *Modiolus imbricatus* Sowerby, *M. subangustissima* Dacque, *M.* (*Pharomytilus*) sp. cf. *M.* (*P.*) *perplicatus* (Etallon), *Mytilus subpectinatus* d'Orbigny, *Ostrea dieneri* Blanckenhorn, *O. ouremensis* Chofat, *O. suborbicularis* Roemer, *O. siphax coquand*, *O. thurmanni* Etallon, *O.* sp., *Pholadomya aubryi* Douville, *P. protei* (Brongniart), *P.* sp., *Pinna* sp. cf. *P. stoliczakai* Cox, *Praeonia rhomboidalis* (Phillips), *Protocardia somaliensis* Cox.

**Gastropods:** *Cerithium* sp. cf. *C. moreanum* Buvignier, *Globularia hemisphaerica* Roemer, *Globularia* sp., *Natica hemisphaerica* Roemer, *N.* sp., *Nerinea acreon* d'Orbigny, *N. binodosa* Etallon, *N.* sp. cf. *N. hoheneggeri* Peters, *N.* sp. cf. *N. nodosa* Voltz, *N.* sp. cf. *N. schloenbadi* Gemmellaro, *N.* sp. cf. *N. sculpta* Etallon, *Nerinella retrogressa* Etallon, *Pseudomelania* sp. *Tylostoma* sp.

**Cephalopods:** *Perisphinctes* sp. aff. *P. praestenococylus* Waagen, *P.* sp. cf. *P. virguloides* Waagen, *P.* (*Virgatites*) sp. cf. *P.* (*V.*) *dorsoplanus* (Burckhardt).

**Echinoderms:** *Cidaridae* sp., *Cidaris cenomanensis* Cotteau, *C. glandarius* Lang, *Hemicidaris* (*Hypodiadema*) *macfadyeni* (Currie), *Pseudocidaris thurmanni* Etallon.

**Indeterminate fossils:** *Stromatoporoids*, *corals*, *bivalves*, *gastropods*, *plant debris*.

## Age

The occurrence of *Daghanirhynchia* ? sp., *Homomya inornata* (Sowerby), (Bathonian); *Burmhirhynchia* ? sp., *Eligmus* sp. cf. *E. aualites* (Stefanini), *E.* sp. cf. *E. rollandi* Douville, (Bathonian-Callovian); *Mactromya aequalis* Agassiz, *M.* sp., (Bathonian-Portlandian); *Brachidontes* (*Arcomytilus*) *laitmairensis* (de Loriol), *Ceratomya* sp. cf. *C. kiliani* (Rollier), *C.* sp. cf. *C. wimmisensis* (Gillieron), *Chlamys* (*Chlamys*) *curvivarians* Dietrich, *Inoperna perplicata* (Etallon), (Callovian-Oxfordian); *Haplophragmium coprolithiforme sequanum* (Mohler), *Somalirhynchia africana* Weir, *S. africana* var. *mesoloba* Muir-Wood, *Lopha solitaria* Sowerby, (Ox-

fordian); *Nerinea* sp. cf. *N. nodosa* Voltz, (Oxfordian-Kimmeridgian); *Synastrea* sp. cf. *S. conicinna* Goldfuss, *Lima* (*Plagiostoma*) *harronis* Dacque, *Nerinea* sp. cf. *N. sculpta* Etallon, *Pseudocidaris thurmanni* Etallon, (Kimmeridgian), in the Amran sequence [6,8,9], indicates that the Amran Formation ranges in age from the Bathonian to the Kimmeridgian. However, the benthic foraminifers which are recorded in the present study and whose stratigraphical ranges are shown in Table 2, date the Amran as Bajocian-Kimmeridgian. Furthermore, as the Amran conformably underlies the Madbi Formation which contains fossils of Kimmeridgian age, the Amran formation is dated as Middle-Late Jurassic (Bajocian-early Kimmeridgian).

### Contacts

In the type area as well as in other localities that lie in the centres of the Jurassic sedimentary basins (Fig. 1), both the lower and upper contacts are gradational and conformable. The contact with the underlying Affar Formation is delineated at the first appearance of the limestone of the Amran Formation. The upper contact is placed at the first appearance of the marly clastics or the evaporities of the Madbi and Sabatain Formations, respectively. In localities lying near the margins of the sedimentary basins, the lower and/or the upper contact may be unconformable.

### Distribution

The Amran Formation is widely exposed and its calcareous rocks are distributed in most parts of the Yemen Arab Republic.

### Remarks

Beydoun [4,5] equated the Shuqra Formation in the People's Democratic Republic of Yemen, with the Amran Limestone "Series" in the Yemen Arab Republic. This is accepted and followed in the present study as the two units are lithologically and chronologically similar.

El-Anbaawy [7] recognized, in the Amran sequence of the Yemen Arab Republic, seventeen facies associations which he included in four formations and two members (Table 1). The Wadi Al-Ahjur Formation, Jabal Salab Formation, Thoma Member and Wadi Naham Member of these units were suggested as new. However, he delineated his new units on the basis of their inferred facies characteristics; this however, violates the rules of stratigraphic nomenclature. Lithostratigraphic units should be defined on the basis of their observable lithology and mappability (in the case of formations). Inferred geologic history and depositional environment have no place in the definition of the lithostratigraphic units [10, Articles 22 a, d and 24 b]. Accordingly, all the new units suggested by El-Anbaawy [7] are informal, and thus invalid and they should be dropped from the Jurassic stratigraphy of Yemen Arab Republic [10, Article 20]. They are, therefore, rejected in the present study.

## **Madbi / Sabaain Formations**

The Madbi and Sabatain Formations are two laterally equivalent units which accommodate the transitional beds that lie between the Amran Limestone and the Tawilah Sandstone. The Madbi includes the marly clastics which were laid down in shallow open-marine environment and distributed in most parts of the Yemen Arab Republic. The Sabatain Formation on the other hand, includes the evaporites which were deposited in an isolated basin (or basins) and restricted to the eastern regions.

### **Madbi Formation**

#### **Definition**

This unit was introduced by Beydoun [4,5]. Its type section lies at Jabal Madbi in the People's Democratic Republic of Yemen where it consists of fossiliferous, yellow, gray silty, locally gypsiferous marls with thin rubbly and marly limestone and occasional thin gypsum interbeds. Its thickness ranges from 60 to 290 m.

#### **Reference section in the Yemen Arab Republic**

A reference section for the Madbi Formation in the Yemen Arab Republic is chosen at the northern side of Wadi Surdud near the junction with Wadi Al-Ahjar (Fig. 1).

Approx. lat. 15°      16' N  
Approx. long. 43°    42' E

#### **Lithology**

In the Yemen Arab Republic the Madbi Formation is represented by a widely variable lithology. In the area of the reference section (Wadi Surdud), it consists of about 60 m of light green to light yellow shale and some sandy beds that enclose alternating layers of black shale and marl. In the western regions, it consists of shale with gypsum, sandstone and dark bituminous shale interbeds. In the southern regions, it is represented by shale with marl and limestone interbeds. In the northern regions, the sandstone is better developed where this unit consists of fossiliferous sandstone with gypsum lenses and sandy limestone interbeds [6,8].

#### **Contacts**

In the type locality in the People's Democratic Republic of Yemen, the lower contact with the Shuqra Formation, and the upper contact with Naifa Formation are conformable [4,5]. Similarly, in the Yemen Arab Republic, the contacts with the underlying Amran Formation and the overlying Tawilah Formation are gradational and conformable.

## Fossils

In the People's Democratic Republic of Yemen, Beydoun [4,5] recorded the following fossils:

**Foraminifera:** *Valvulinella* (= *Kurnubia*) *jurassica* Henson.

**Brachiopoda:** *Daghanirhynchia macfadyeni*, *Somalirhynchia* sp. cf. *S. africana jordanica*, *S.* sp. cf. *S. africana smellei*, *Terebratula aualites* Stefanini.

**Gastropods:** *Proconulus ambalensis* (Weir).

**Bivalves:** *Astarte (Coelastarte) scyrtalis* Holdaus, *Exogyra fourtaui* Stefanini, *Gryphaea balli* ? (Stefanini), *Inoceramus* sp. cf. *I. suprajurensis* Thurmann, *Lopha marshi* (Sowerby), *L.* sp. cf. *L. solitaria* (Sowerby), *Modiolus imbricatus* (Sowerby), *Ostrea (Liostrea)* sp. cf. *O. (L.) moreana* Buvignier, *O. (L.) wagurensis* Cox, *Posidonis somaliensis* Cox.

**Cephalopoda:** *Ataxioceras desmoides* Wegele, *Idoceras* sp. cf. *I. farquharsoni* Spath, *Perisphinctes mombassanua* Dacque, *P. (Divisosphinctes)* sp. cf. *P.(D) inaequalis* (Spath), *P. (Pachysphinctes) robustus* Spath, *Belemnopsis tangenensis* (Futterer).

In the Yemen Arab Republic, Geukens [8] recorded in the beds equivalent to the Madbi Formation, some fossils such as: *Ceratomya* sp. cf. *C. plicata* (Agassiz), *Exogyra* sp., *Lima (Plagiostoma) harronis* (Dacque), *Lopha solitaria* (Sowerby), *Modiolus jurensis* (Roemer), *Trochalia* sp. cf. *T. yemenensis* (Basse), *Nerinea* sp., *Somalirhynchia africana* (Weir), *Terebratula* sp. and plant remains.

## Age

On the basis of the occurrence of *Modiolus jurensis* (Roemer) and *Lima (Plagiostoma) harronis* (Dacque), (Kimmeridgian), and as the Madbi Formation conformably overlies the Amran Formation (Bajocian-early Kimmeridgian) in the Yemen Arab Republic, and underlies the Naifa Formation (Tithonian = Portlandian) in the People's Democratic Republic of Yemen, the Madbi Formation in the Yemen Arab Republic is dated as late Kimmeridgian. A similar age assignment (Kimmeridgian) was also suggested by Beydoun [4,5] on the basis of a rich fossil assemblage recorded in this rock unit in the People's Democratic Republic of Yemen.

## Distribution

In the Yemen Arab Republic, the Madbi Formation occurs in the northern, southern and western regions.

## **Sabatain Formation**

### **Definition**

The Sabatain Formation is the lateral equivalent of the Madbi Formation. It was introduced by Wetzel and Morton, 1950, in unpublished report [4,11]. Its type locality lies in the salt-domes area in the western and northwestern parts of the People's Democratic Republic of Yemen. At that locality, the Sabatain Formation consists of evaporites with clastics. Its lower part consists of rock salt which is not completely exposed and which is overlain by fossiliferous shales, followed upwards by gypsum that laterally grades into sandstone and shales. This formation was named after Ramlat as Sabatain desert in which some of the salt domes are exposed.

### **Reference section in the Yemen Arab Republic**

The sequence exposed at the Safir Salt Dome which lies about 85 km to the east of Ma'rib Town (Fig. 1) is taken as the reference section for the Sabatain Formation in the Yemen Arab Republic.

Approx. lat.	15°	41'	N
Approx. long.	46°	09'	E

### **Lithology**

The succession of the Sabatain Formation at Safir Dome is similar to that of the type area in the People's Democratic Republic of Yemen. In both localities it consists of a basal rock salt unit which is overlain by bituminous shales, several meters of gypsum, and yellow gray argillaceous and calcareous shale [6,8].

### **Lower contact**

This contact with the Shuqra Formation (in the People's Democratic Republic of Yemen) and the Amran Formation (in the Yemen Arab Republic) is not exposed.

### **Upper contact**

At the type area, in the People's Democratic Republic of Yemen, the Sabatain Formation is conformably overlain by the Naifa Formation. At the reference section in the Yemen Arab Republic (Safir Dome), the overlying beds are covered by sand dunes. But in Al-Ghiras area (Fig. 1), the Sabatain Formation is conformably overlain by the Tawilah Formation.

### **Fossils**

In the present study, a rich assemblage of fossil fish is recorded in the black shales of the Sabatain Formation at Khulaqah Quarry, about 40 km northeast of

Sana'a (Fig. 1). The preliminary identification of the recorded fish was carried out by both Dr. D. Bardack of the Field Museum, Chicago (who identified most of the specimens), and Dr. J.G. Maisey of the American Museum of Natural History, New York, U.S.A. (who identified some specimens), (personal communications). The recorded fishes belong to the following groups: Amiiiforms, Aspidorhynchids, Dercetids, Enchodontids, Ichthyodectids, Leptolepids, Macrosemiids, *Pleuropholis* spp., Pycnodonts, Semionotoids, and Teleosteans (Bardack and Maisey, personal communications).

Also, Basse *et al.* [12] described the fossil fish *Pleuropholis bassei* Lehman in the same horizon near Al-Harrah Village, Al-Ghiras area (Fig. 1). In addition to the fossil fish, the shales of the Sabatain Formation in Al-Ghiras and Safir areas, provided the following spores and pollen grains: *Glassopollis* (= *Tetradopollenites*) *reclusus* (Thiergart), *Concavisporites* sp., *Entylissa* sp., *Ephedra strobilacea*, *Gleicheniidites feronensis* (Delcourt and Sprumont), *Inaperturopollenites* sp., *Monosulcites* sp., *Sporites adriennis mesozoicus* Thiergart, *Sporites dorogensis*, *Striatissporites* sp., *Tricolpites* sp. aff. *T. troedsonii*, and *Trisaccites* sp. [8,9].

### Age

The above-mentioned fossils date the Sabatain Formation as Late Jurassic [8,9]. The fish assemblage recorded in the present study substantiates this age. Furthermore, as the Sabatain Formation is considered as the lateral equivalent of the Madbi Formation which is on paleontological basis given a late Kimmeridgian age, the Sabatain Formation is here dated as late Kimmeridgian.

### Distribution

The Sabatain Formation occurs in the western and northwestern parts of the People's Democratic Republic of Yemen in piercement salt domes and continues in the eastern regions of the Yemen Arab Republic. The Sabatain Formation is correlatable with both the Hith (Tithonian) and slightly earlier commencing Gotnia (Kimmeridgian-Tithonian) Formations of Arabia and Iraq, respectively, which consist of anhydrite. This means that the isolated basins in which these evaporites were deposited, were widely distributed in the area as a result of the retreat of the sea at the close of the Jurassic Period.

### Remarks

Facies differences between the Sabatain and its laterally equivalent Madbi Formation may be due to the presence of a barrier (or barriers) which led to evaporitic conditions for the Sabatain, and shallow open-sea conditions for the Madbi. This barrier was subsequently removed during the early deposition of the overlying Naifa Formation and allowed the Naifa Limestone to spread over the salt domes area [4,5]. However, no beds similar to the Naifa Formation are present in the Yemen Arab

Republic. This indicates that the marine transgression which deposited the Naifa in the People's Democratic Republic of Yemen, did not reach the Yemen Arab Republic. Instead, continental conditions prevailed during which the gravelly sandstones of the Ghiras Member (of the Tawilah Formation) were laid down.

Alternatively, the rise of evaporitic conditions may have been partly or additionally due to the occurrence of submarine plateau conditions where stagnation with rapid evaporation prevailed in the absence of deep water current circulation [4,5].

### **Subdivisions**

Beydoun [4,5] subdivided the Sabatain Formation in the People's Democratic Republic of Yemen into four members which are in ascending order: the Shabwa, Layadim, 'Ayad and M'qah Members. The 'Ayad and M'qah Members are laterally equivalent and intertonguing. These four members are also recognized in the Yemen Arab Republic mainly at Safir and Al-Ghiras areas. A brief description of each of these units is given below, mainly after [4-6,8].

#### **Shabwa Salt Member**

This is the lowest member of the Sabatain Formation and it occurs in all salt domes in both the People's Democratic Republic of Yemen and the Yemen Arab Republic. It was introduced by Wetzel and Morton, 1950, in unpublished report [4, 11]. The base of the Shabwa Member is not exposed and generally only the upper 10-20 m are exposed. This member consists of rock salt which has layered structure, gray striations and bituminous stains. The salt is of depositional origin [4-6, 13]. It was named after the Shabwa Salt Dome, People's Democratic Republic of Yemen (lat. 15° 22' N, long. 47° 00' E) and it is conformably overlain by the Layadim Shale Member.

In the Yemen Arab Republic, the Shabwa Salt Member is exposed at Safir area (Fig. 1) where it forms the central part of Safir Salt Dome. It has a similar lithology to that of the type section in the People's Democratic Republic of Yemen. At Al-Ghiras area, this member is not exposed and field observations indicate that it is most probably not represented in this locality.

On the basis of its stratigraphical position the present rock unit is considered to be of Late Jurassic age (late Kimmeridgian).

#### **Layadim Shale Member**

This member was introduced by Wetzel and Morton, 1950, in unpublished report [4,11]. It consists of variegated shales, commonly black, papery, bituminous, occasionally sandy, micaceous, with thin marl, shaly limestone, dolomitic limestone and gilsonite thin interbeds. In some salt domes this unit becomes marly, locally

shaly and contains salt streaks. Its thickness varies from about 7 m to 68.5 m. It is conformably underlain and overlain by the Shabwa and the 'Ayad (or M'qah) Members, respectively. This member is recognized in all salt domes of the area. It was named after Al 'Ayadim Salt Dome, in the northwestern part of the People's Democratic Republic of Yemen. In the Shabwa Salt Dome, the Layadim Member provided the fish *Anaethalion*, and abundant *Etheria* and *Spongistroma* of Late Jurassic age.

In the Yemen Arab Republic, the Layadim Shale Member occurs in both the Safir and Al-Ghiras areas. At Khulaqah Quarry (Al-Ghiras area), only the upper 0.5 - 1 m of this unit is exposed where it consists of black, papery, bituminous shale with occasional pyrite crystals. It is worth mentioning that all the fossil fish, spores and pollen grains recorded in the Sabatain Formation, were found in the present member. These fossils date the Layadim Member as Late Jurassic. However, as this member is one of the constituent units of the Sabatain Formation which is here assigned to the late Kimmeridgian, the Layadim Member is considered to be of late Kimmeridgian age.

#### **'Ayad Gypsum Member**

This is one of the two upper units of the Sabatain Formation the other being the M'qah Sandstone Member which is the lateral variant of the 'Ayad Member. This member was introduced by Wetzel and Morton in 1950, in unpublished report [4,11]. It consists of white to yellow bedded gypsum, with occasional thin dolomite, and has argillaceous and bituminous limestone interbeds. It conformably overlies the Layadim Shale Member, and underlies the Naifa Formation. Its thickness is variable being about 230 m at its maximum development at the 'Iyadh Salt Dome. In most other domes, this member is incompletely preserved or absent owing to erosion, and only at the 'Iyadh Salt Dome is in actual contact with the overlying Naifa Formation. It was named after the 'Iyadh Salt Dome in the People's Democratic Republic of Yemen (lat. 14° 59' N, long. 46° 49' E).

In the Yemen Arab Republic, the 'Ayad Member is well developed at Al-Ghiras area where it is represented by thick gypsum lenses. At Khulaqah Quarry, it consists of about 60 m of gypsum with marl and clay interbeds. In this locality, it conformably overlies the Layadim Shale Member and underlies the Ghiras Sandstone Member. At the Safir Dome, the member is incompletely preserved and it is replaced by its laterally equivalent M'qah Sandstone Member.

On the basis of its stratigraphical position the 'Ayad Gypsum Member is assigned to the late Kimmeridgian.

#### **M'qah Sandstone Member**

This is the lateral equivalent of the 'Ayad Gypsum Member. It was introduced

by Wetzel and Morton, 1950, in unpublished report [4,11]. The M'qah Member occurs in the Milh Maq'ah Dome and it is partly represented in the Shabwa Dome as a tongue in the 'Ayad Member. At its type section (Milh Maq'ah Dome) this member consists of about 150 m of coarse, greenish, ripple-marked sandstone alternating with micaceous shales with plant remains. Beds of clayey limestone, dolomite and marl are found at various levels; gypsum is present at the base and top of this member and in bands at various levels within the clastic sequence.

In the Yemen Republic, the M'qah Member is exposed in the Safir Dome where it attains a thickness of about 150 m and consists of clayey sandstone which is very rich with gypsum, followed upwards by alternating gray, sandy shale and purple sandstone. The upper parts are covered with Recent dunes.

On the basis of its stratigraphical position, the M'qah Member is assigned to the late Kimmeridgian.

### **Paleogeography**

As mentioned by Geukens [6,8] and El-Nakhal [3], the most important marine transgression in the geologic history of the Yemen Arab Republic took place during the Middle-Late Jurassic when the sea covered the entire country and a thick calcareous sequence of the Surdud Group was deposited. The sequence of this group seems to be deposited in different sedimentary basins. Geukens [8] recognized at least three of these basins the subsidence centres of which lie in the Jabal Maswar-Wadi La'ah (around Sana'a), west of the Al-Aridha (southwest of Yemen) and the Ramlat as Sabatain (east of Yemen), areas (Fig. 1). At the close of the Jurassic Period, a marine regression took place and isolated basins began to form in the eastern regions which led to the deposition of evaporites of the Sabatain Formation. Similar conditions also prevailed during this time in Saudi Arabia, Qatar, Abu Dhabi, Kuwait, Iraq and Iran where were deposited the anhydrites (and some halites) of the Hith an Gotnia Formations. This indicates that the isolated basins and the evaporitic conditions were widespread during the Late Jurassic in Arabia and adjacent regions due to the presence of numerous barriers.

Outside the area of the isolated basins, in the rest of both the Yemen Arab Republic and the People's Democratic Republic of Yemen, shallow open-sea conditions prevailed where the shales, marls, limestones and sandstones of the Madbi Formation were laid down. In the People's Democratic Republic of Yemen, the deposition of the Madbi Formation was followed by a marine transgression during which the Naifa Formation was deposited. This marine transgression did not reach the Yemen Arab Republic and continental conditions prevailed at that time.

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## مجموعة سُرْدُد، وحدة صخرية جديدة من العمر الجوراسي في الجمهورية العربية اليمنية حامد أحمد النخال

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(استلم في ٧ صفر ١٤٠٩هـ، قبل للنشر في ٢٤ ذو القعدة ١٤٠٩هـ)

ملخص البحث. يُقترح في الدراسة الحالية إدخال مجموعة سُرْدُد كوحدة صخرية جديدة لتضم تكوين العمران والطبقات الانتقالية الواقعة بين تكويني العمران والطويلة في الجمهورية العربية اليمنية. ويتكون تكوين العمران من صخور جيرية أحفورية تحتوي على راقات من المارل والطين الصفحي والغرين، وعلى أساس المحتوى الأحفوري والوضع الطبقي فقد نُسب عمره إلى الجوراسي المتوسط والمتأخر. أما الطبقات الانتقالية فتتكون من متبخرات وصخور فتاتية مارلية. وينحصر وجود المتبخرات في المناطق الشرقية من اليمن وقد ضُمت في تكوين السبعين. أما الطبقات الفتاتية المارلية والتي وُضعت في تكوين المدبي، فتوجد في باقي أجزاء اليمن. يتضاهى تكوينا السبعين والمدبي جانبياً، وعلى أساس محتواهما الأحفوري ووضعها الطبقي فقد اعتبرا من العصر الجوراسي المتأخر. ويُقسم تكوين السبعين إلى أربعة أفراد وهي من الأقدم إلى الأحدث: ملح شبوة، طين عياديم، جبس عياد، رمل معقة، والفردان الأخيران متضاهيان جانبياً ويتداخلان في بعض المناطق. لقد صُوّهي تكوين السبعين بتكويني هث وقطنية اللذان يتكونان من الأنهدرايت ويوجدان في الجزيرة العربية والعراق، على التوالي، مما يشير إلى أن بيئة المتبخرات كانت واسعة الانتشار في هذه المنطقة في نهاية العصر الجوراسي. لقد دُعم في الدراسة الحالية العمر الجيولوجي الذي نُسب له هذا التكوين وكذلك التكوينان المضاهيان له (هث وقطنية)، حيث تم تسجيل العديد من أحافير الأسماك.