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# Review of and Contribution to the Stratigraphy of the Cenozoic Igneous Rocks in the Republic of Yemen

**Abstract:** In Yemen the Cenozoic igneous rocks consist of intrusive and extrusive rocks with interlayered sediments, all of which are included within the Manakhah Group (latest Cretaceous-Holocene). This group is subdivided into the Haraz Formation which includes the latest Cretaceous-Tertiary volcanics and the interlayered sediments, the Aden Formation which includes the Late Tertiary-Holocene volcanics, and the Bura' Formation which includes the Tertiary alkaline granites. The Manakhah Group, Haraz and Bura' Formations are introduced here as new units. The Haraz Formation replaces the informal names: Trap Series, Yemen Volcanics, and Aden Trap Series. The Aden Formation is a readaptation of the term Aden Volcanic Series. A stratotype for the Aden Formation is designated in the Shuqra-Ahwar area.

**Keywords:** Stratigraphy, Cenozoic, Igneous rocks, Yemen.

## Introduction

The Republic of Yemen occupies the southwestern corner of the Arabian Peninsula bordering the Red Sea and the Gulf of Aden (Fig. 1). It is a new country resulting from the union of the former "Yemen Arab Republic" (North Yemen), and the former "People's Democratic Republic of Yemen" (South Yemen). In the present study, the former "Yemen Arab Republic" will be referred to as the northern provinces, and the former "People's Democratic Republic of Yemen" will be referred to as the southern provinces.

The present work is a part of a comprehensive study concerned with the revision of the stratigraphy of the Phanerozoic Eonothem in the Republic of Yemen. It has been planned to publish this study in

مراجعة وإضافة لطبقية صخور حقب الحياة الحديثة النارية في

الجمهورية اليمنية

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المستخلص: تتكون الصخور النارية التابعة لحقب الحياة الحديثة في الجمهورية اليمنية من صخور سطحية وأخرى متداخلة، هذا بالإضافة إلى طبقات من الصخور الرسوبية الممتدة بينهما. ويمتد العمر الجيولوجي لهذه الصخور من أواخر العصر الطباشيري وحتى العهد الحديث، وقد وضعت جميعها في مجموعة مناخة، وتوجد أغلب مكاشفها في غرب الجمهورية اليمنية. وقسمت مجموعة مناخة إلى ثلاثة تكوينات وهي: حراز، عدن وبرع، ويضم تكوين حراز الصخور البركانية والفتاتيات النارية، وكذلك الصخور الرسوبية الممتدة بينها، والتي تتبع جميعها في عمرها الجيولوجي أواخر العصر الطباشيري والعصر الثلاثي. ويحل هذا الاسم محل كل من "سلسلة تراب"، و"بركانيات اليمن" في المحافظات الشمالية، وسلسلة تراب عدن في المحافظات الجنوبية، والتي لا تتفق وقوانين التسمية الطباقية. ويقع القطاع النمطي لتكوين حراز في منطقة مناخة الجبلية، وتمتد أغلب مكاشفها في غرب الجمهورية اليمنية. ويصل سمكه إلى 1100-2000 م في المحافظات الجنوبية والشمالية على التوالي. أما (تكوين عدن) فيتكون من الصخور البركانية التي تمتد في عمرها من أواخر عهد الميوسين وحتى العهد الحديث. وتتكون هذه الصخور من طفوح بركانية وفتاتيات نارية مع وجود العديد من المخاريط البركانية. وتوجد مكاشف هذا التكوين في المنطقة الساحلية من المحافظات الجنوبية ممتدة من باب المندب غرباً وحتى منطقة قصيعر - سيحون شرقاً. أما في المحافظات الشمالية فتتركز مكاشفها في ثلاث مناطق أو حقول، وهي: مأرب - صرواح، وصنعاء - عمران ودمار - رادع. وقد اختيرت في الدراسة المكاشف الموجودة بين شقرة والأحوار، في المحافظات الجنوبية لتكون القطاع النمطي لتكوين عدن. ويضم (تكوين برع) الجرانيت القلوي الذي يتبع في عمره العصر الثلاثي (أوليغوسين - ميوسين)، وتوجد أغلب مكاشفها وكذلك قطاعه النمطي في المرتفعات الغربية بموازاة البحر الأحمر. وقد حققت صخوره الجرانيتية في تكوينات عديدة ومختلفة مثل تكوينات عفار (أوائل الجوراسي)، وعمران (أواسط - أواخر الجوراسي)، والطويلة (طباشيري - باليوسين)، وحراز (أواخر الطباشيري - الثلاثي). هذا ويعتقد أن النشاط الناري في اليمن قد بدأ في أواخر العصر الطباشيري وأوائل العصر الثلاثي، واستمر بشكل متقطع حتى العهد الحديث، ولكن أغلب الصخور النارية حققت وتدفقت خلال عهدي الأوليغوسين والميوسين. إلا أن مجموعة مناخة و تكويني حراز وبرع، هي وحدات صخرية جديدة تمت دراستها لأول مرة في هذه الدراسة.

كلمات مدخلية: طبقية، الصخور النارية، حقب الحياة الحديثة، اليمن.

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a series of successive publications that treat the three Phanerozoic erathems. The present part is mainly devoted to the revision of the stratigraphy of the Cenozoic igneous rocks in Yemen. The stratigraphy of the Paleozoic, Mesozoic, and the Cenozoic sedimentary rocks has been revised elsewhere (El Nakhal, 1996, 19997, 1998).

The present study aims to compile the available stratigraphic information on the Cenozoic igneous rocks in Yemen, correlate the equivalent rock units in the two parts of Yemen applying the same terminology whenever this is possible, and to give formal names for the informal names whenever this is necessary.

**Manakhah Group:**

This group is introduced as a new unit to include the latest Cretaceous-Holocene igneous rocks and the interlayered sediments in the Republic of Yemen. It is named after its type area, the Manakhah mountainous region (lat. 15° 05' N, long. 43° 41' 30'' E) which lies about 60 km west-southwest Sana'a City (Fig. 1). Main exposures of the group are found in the western regions of Yemen. Minor exposures are also scattered elsewhere in the country. Its thickness varies from place to place. The maximum reported thickness reaches 2000 - 3000 m in the Sana'a region (Davison *et al.*, 1994). The lower contact with the Tawilah Formation is conformable (El-Nakhal, 1991). In its type area the Manakhah Group is not overlain by other rock units. The present group is divided into three formations, which are as follows: (Fig. 2)

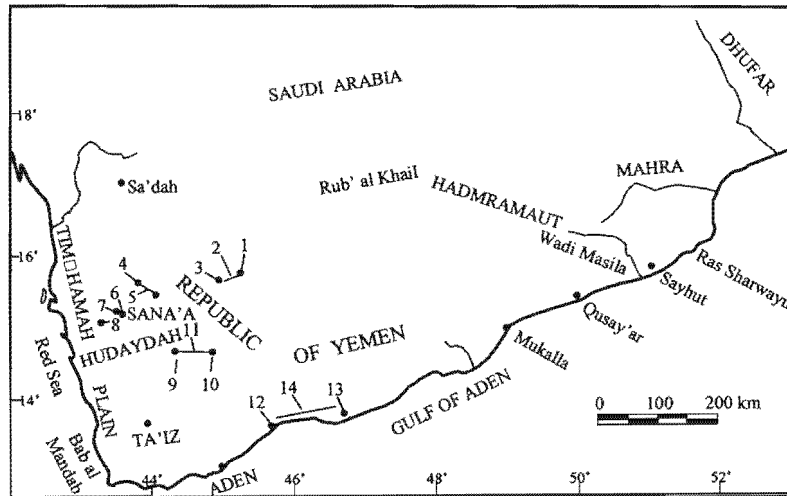


Fig. 1 Outline map of the Republic of Yemen

**Lithostratigraphy**

In Yemen, the igneous rocks consist of intrusive and extrusive rocks with interlayered sediments, which are included within the Manakhah Group.

is conformable (El-Nakhal, 1991). In its type area the Manakhah Group is not overlain by other rock units. The present group is divided into three formations, which are as follows: (Fig. 2)

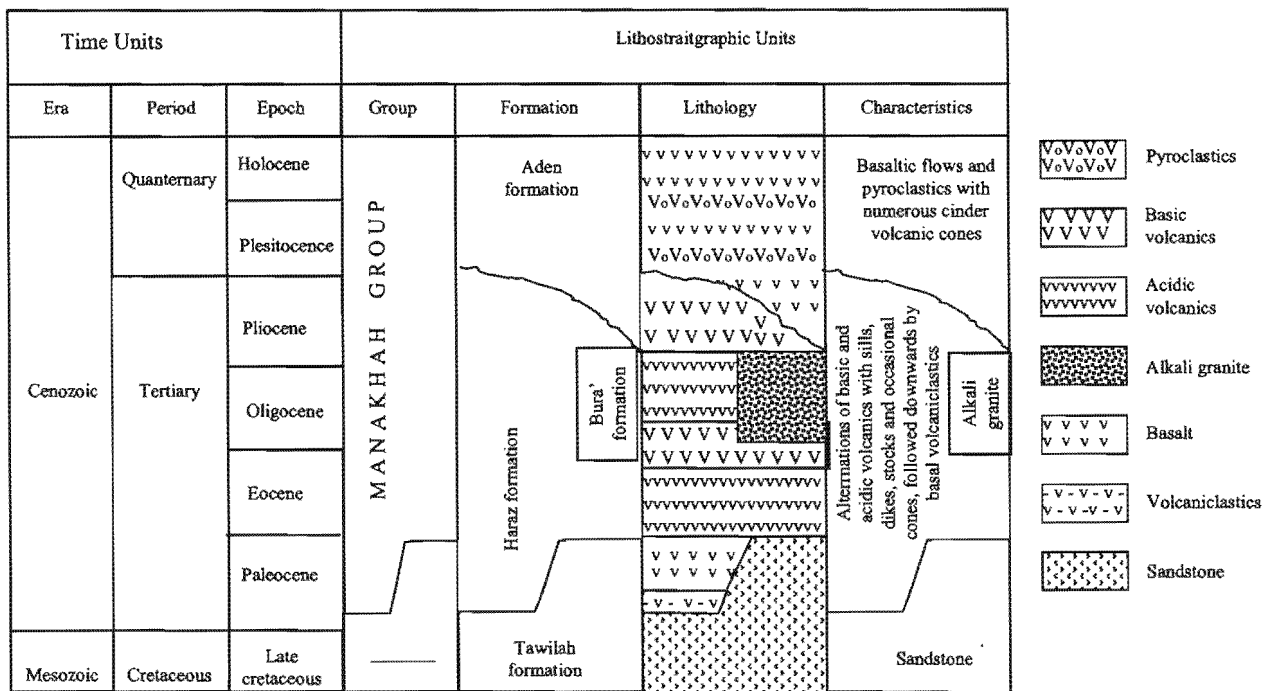


Fig. 2 Lithostratigraphic columnar section showing subdivisions of the Manakhah group in the Republic of Yemen

- 1) Haraz Formation: includes the latest Cretaceous-Tertiary volcanics and the interlayered sediments.
- 2) Aden Formation: includes the Late Tertiary-Holocene volcanics.
- 3) Bura' Formation: includes the Tertiary granites.

**Remarks:**

It is believed that the volcanic activity in Yemen had begun during the latest Cretaceous and earliest Tertiary (Geukens 1960, 1966, Greenwood and Bleackley 1967, Beydoun and Greenwood 1968, El-Nakhal 1991) and intermittently continued to the Holocene, but the bulk of the igneous rocks was extruded and intruded during the Oligocene-Miocene time. Manetti *et al* (1991) and Davison *et al* (1994) pointed out that the northern provinces of Yemen during the last 30 Ma have been the site of intense magmatic activity and flood volcanism.

**Haraz Formation:**

The Haraz Formation is introduced to replace the informal terms: Trap Series of Geukens (1960, 1966), and Yemen Volcanics of Grolier and Overstreet (1978) in the northern provinces, and the Aden Trap Series of Greenwood and Bleackley (1967) in the southern provinces (Table 1). It consists of basal volcanoclastics followed upwards by alternative sequences of basic and acidic volcanics (Fig. 3). The volcanoclastics include dark gray and greenish tuffs, black shale, coal interbeds, limestone rich with gastropod shells, basaltic pillow lavas, and paleosol on the top of the sequence. The basic volcanics are composed of basalt and pyroclastics with sills, and interbedded sediments. The acidic volcanics consist of ignimbrites and pyroclastics with dikes, stocks, occasional cones, and water-laid sandy tuffaceous intercalations and algal reef (Kruck and Schäffer, 1991).

**Table 1** Correlation of the suggested subdivision of the Manakha Group with previous ones

Time Units		Blanford (1869)	Lamare. (1936)	Geukens (1960,1966)	Greenwood and Beackley (1967), Beydoun and Greenwood (1978)	Grolier and Overstreet (1978)	Kruck (1984)	Kruck and others (1984)	Kruck and Schaffer (1991)	Present Study
Era	Period									
Cenozoic	Quaternary	Aden volcanic series	Recent and sub-recent eruptions	Recent volcanoes	Aden volcanic series	Basalt flows and dikes	Basaltic flows and cones	Basaltic flows and cones	Quaternary volcanics	Aden formation
	Tertiary	Volcanics of the highlands	Intermediate eruptions Major stratoid extrusives (basalts and rhyolites)	Trap series Recent granites and lacoliths	Aden trap series Alkali granite	Yemen volcanics Alkali granite	Pyroclastics, basaltic flows and ignimbrite Alkali granite	Basaltic flows and pyroclastics Alkali granites and syenite	Acidic and basic volcanics Granite and alkali granite	MANAKHAH GROUP Haraz formation Bura' formation
Mesozoic	Cretaceous	—	Tawilah series	Tawilah group	Tawilah group	Tawilah group	Tawilah sandstone	Tawilah sandstone	Tawilah sandstone	

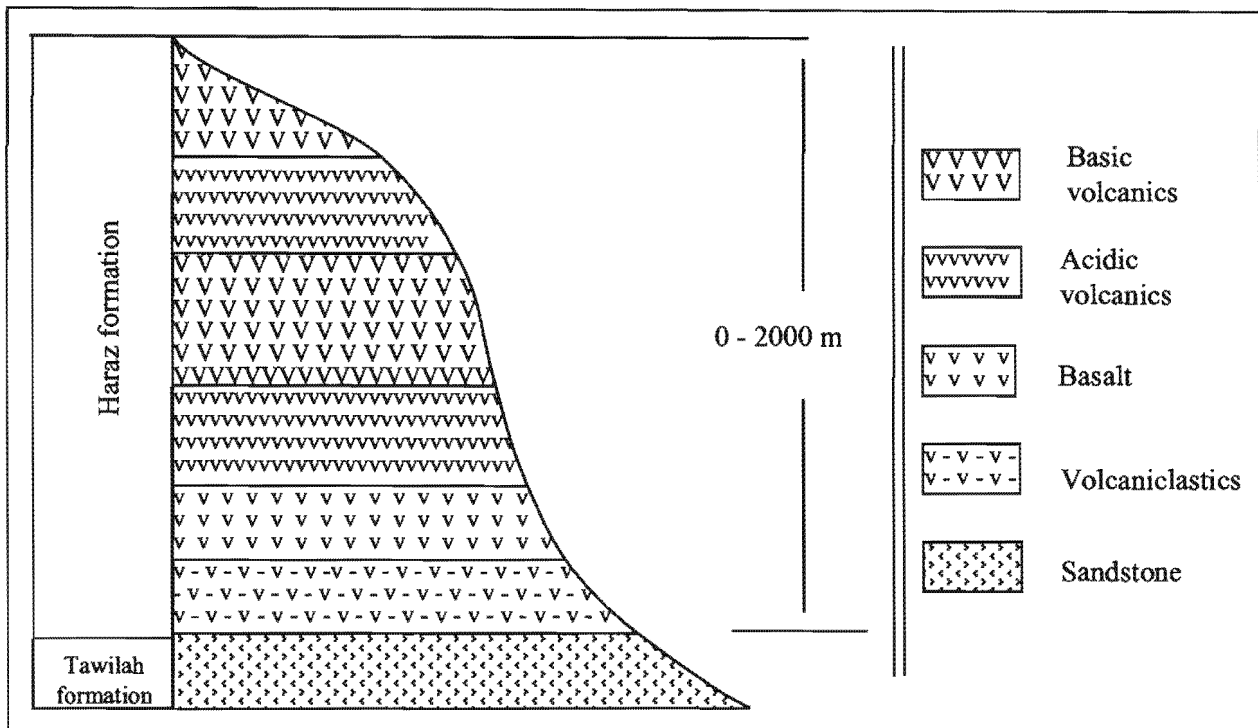


Fig. 3 Lithostratigraphic columnar section of the Haraz Formation at its type locality (Jabar Haraz)

The type locality lies in the Manakhah mountainous region (Fig. 1). The sequence which is exposed around Jabal Haraz (lat.  $15^{\circ} 05' 27''$  N, long.  $43^{\circ} 40' 46''$  E) and extends between Jabal Mawjir and Mahall An Narrah Village is designated as the type section. It is difficult to estimate the actual thickness of the Haraz Formation due to repeated faulting. However, at its complete development it reaches 1200 m (Geukens, 1960, 1966), or 2000 m (Grolier and Overstreet, 1978) in the northern provinces, and 1100 m in the southern provinces (Greenwood and Bleackley, 1967, Beydoun and Greenwood, 1968).

Geukens (1960), Menzies *et al* (1990), and El-Nakhhal (1991) referred to the occurrence of lava flows and pyroclastics within the upper parts of the Tawilah Formation. This indicates that the eruption of the volcanics of the Haraz Formation began during the deposition of the sandstones of the Tawilah. Accordingly, the contact between the Haraz and the underlying Tawilah is considered to be conformable.

At its type locality, this formation is not overlain by other rock units. In other localities such as north of Sana'a, and Dhamar area, it is unconformably overlain by the Aden Formation (= Aden Volcanic Series). Similarly, in the southern provinces it is usually not overlain by other rock units, but in a few cases it is unconformably covered by Pliocene deposits.

On the basis of its stratigraphical position and the available radiometric age dating by a number of workers published by Civetta *et al* (1978), Capaldi *et al* (1987), Chiesa *et al* (1989), Menzies *et al* (1990, 1992), and Manetti *et al* (1991), the Haraz Formation is assigned to the latest Cretaceous - Tertiary.

Major exposures of the present formation are found in the western parts of Yemen. Minor exposures are also scattered in the country.

#### Remarks:

Geukens (1960, 1966) followed by subsequent workers included the volcanics and pyroclastics which are equated with the Haraz Formation in the northern provinces, into the Trap Series. In 1978, Grolier and Overstreet replaced it with the term Yemen Volcanics. However, as these two terms violate the rules of the code of stratigraphic nomenclature (1983), Article 29, Remark a, and Article 4, Remark a, both of them are informal and they are here rejected and replaced by the formal new name the Haraz Formation. The Haraz Formation also replaces the term Aden Trap Series of Greenwood and Bleackley (1967) in the southern provinces despite the fact that the latter term has the date priority. This is because the name Aden has been used as a geographical term for three different rock units, namely, the Aden Volcanic Series

(Blanford, 1869), Aden Trap Series (Greenwood and Bleackley, 1967), and Aden Metamorphic Group (Greenwood and Bleackley, 1967). This multiple usage however, does not agree with the rules of the code of stratigraphic nomenclature (1983). According to these rules the term Aden Volcanic Series has the date priority and therefore, it is considered as the senior homonym, whereas the other two terms represent junior homonyms and they should be dropped from the stratigraphy of the Republic of Yemen and be replaced by new names. Furthermore, the use of the term "series" in a lithostratigraphic sense does not conform with the rules of the code of stratigraphic nomenclature (1983). Therefore, in the present study, the Aden Trap Series is replaced by the Haraz Formation, and the Aden Volcanic Series is corrected to the Aden Formation (Table 1).

On the other hand, Geukens (1960, 1966), included the interlayered sediments of the Haraz Formation, in the informal term inter-Trip deposits which he subdivided into four categories as follows:

- 1) Fossiliferous, fresh-water deposits, of probable lacustrine origin, generally containing bituminous beds, plant and fish remains.
- 2) Alluvial deposits with partially carbonized wood fragments.
- 3) Unfossiliferous sandy deposits of probable fluvioeolian origin.
- 4) Paleosol, generally lateritic, at some places developed along plane surfaces, and locally cutting different beds.

The fossiliferous horizons of these deposits bear fresh-water gastropods and ostracods. These are: *Spharium* sp., *Ameriana* sp., *Melanoides* (Tarebia) sp. cf. *M. (T.) acuta* (Sowerby), *Canoda* sp., *Cyprideis* sp., *Cypridopsis* (?) sp., and *Gomphocythere* sp. Geukens (1960, 1966) considered the recorded fossils as being of Oligocene-Miocene age.

In the present study, the interlayered sediments have yielded numerous shells of the gastropod species *Melanoides* (Tarebia) sp. cf. *M. (T.) acuta* (Sowerby) which were recorded in Bani Hushaysh area (northeast Sana'a), and Beer Basha (near Ta'iz). Also imprints of plant leaves, and fish scales and vertebrae are recorded in these deposits along the Sana'a - Kawkaban road (northwest Sana'a). Similarly, fossil frogs, fish, imprints of plant leaves, and spicules of the fresh-water sponge genus *Sponagilla*, are found in the Rida' area (see Fig. 1).

The occurrence of the interlayered deposits within the volcanics of the Haraz Formation indicates that the Cenozoic volcanic activity in Yemen was in the form of intermittent phases, and that there were quiet intervals, some of which were of long duration. During these quiescent periods, the sedimentary intercalations of the Haraz Formation accumulated (Geukens, 1960, 1966).

### Aden Formation:

The Aden Formation is a readaptation of Aden Volcanic Series of Blanford 1869 (Table 1). Blanford applied the term to the immense development of volcanic rocks, amongst which many are recent, occurring along both shores of the southern portion of the Red Sea, and Gulf of Aden. He pointed out that the lava flows differ entirely from all the volcanic rocks of the highlands (= Haraz Formation) and of much later date, though some may be far from recent. Von Wissman and others (1942), and Jaques (1954), recognized two stages of activity, and Beydoun and Greenwood (1968), mentioned that more than one phase of extrusion occurred in the "Aden Volcanic Series".

The present formation is well exposed along much of the coastal parts of the southern provinces from Bab al Mandab on the Red Sea to Qusay'ar-Sayhut area including parts of the plateau. In the northern provinces, major exposures are concentrated in three regions or fields which are the Marib-Sirwah, Sana'a-Amran, and Dhamar-Rida' Fields (see Fig. 1). Minor exposures are also found in different parts of the country. Blanford (1869), however, did not designate a type locality nor a stratotype for his "Aden Volcanic Series". Therefore, in the present study, the volcanic sequence which is exposed between Shuqra ( lat. 13° 21' N, long. 45° 42' E) and Ahwar ( lat. 13° 33' N, long. 46° 37' E), (see Fig. 1), is designated as the stratotype of the Aden Formation. It consists essentially of basaltic flows and pyroclastics with numerous cinder volcanic cones (Fig. 4), and with a thickness reaching about 500 m. In the type locality the basaltic lava is associated with ash and agglomerate, and the basalt here as elsewhere, varies from scoriaceous, vesicular or ropy lava mixed with pyroclastics, to massive, columnar jointed basalt. In the Shuqra-Ahwar area (see Fig. 1) the flows rest upon basement rocks or upon Jurassic and Cretaceous sedimentary rocks (Greenwood and Bleackley, 1967, Beydoun and Greenwood, 1968).

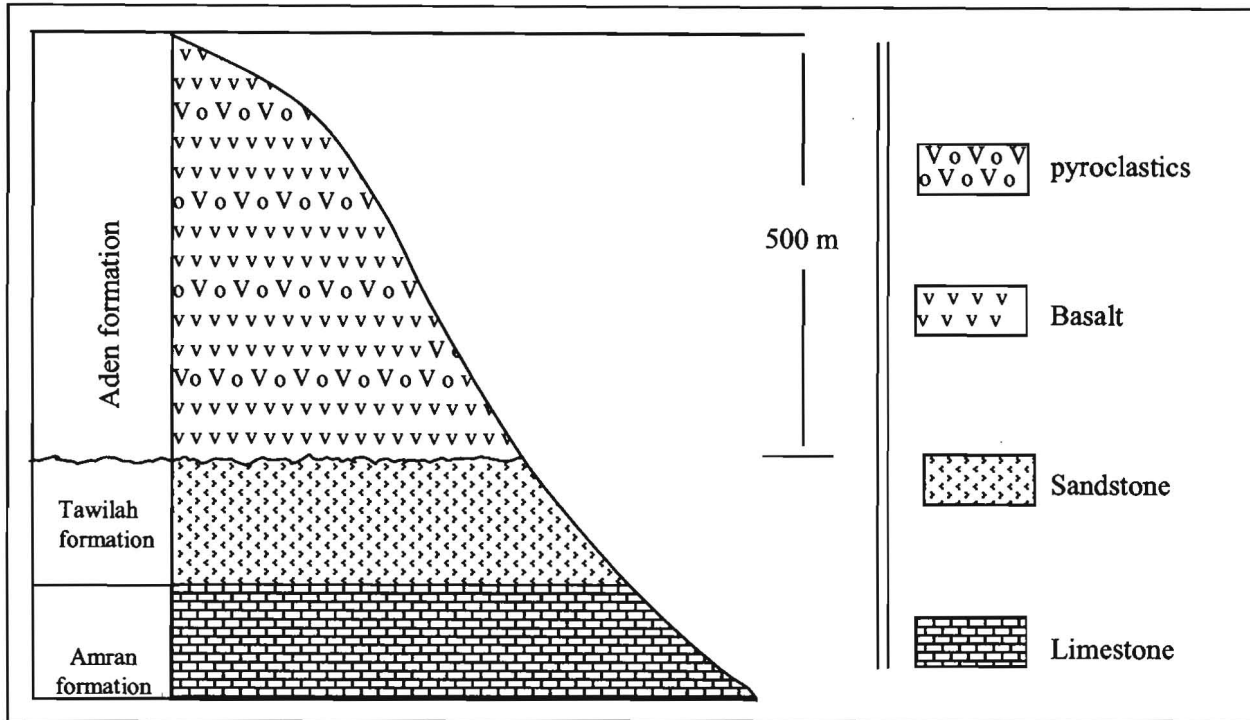


Fig. 4 Lithostratigraphic columnar section of the Aden Formation at its type area (Shuqra-Ahwar area)

Similarly, in the northern provinces the Aden Formation is represented by volcanics, pyroclastics, and numerous cinder volcanic cones. It consists of basic volcanic ash and lapilli, basaltic flows, obsidian, pumice flow and blocks, ignimbrites, with stocks and plugs (Kruck and Schäffer, 1991). In this part of Yemen, the formation is not overlain by other rock units, and it unconformably overlies older rocks such as the Precambrian basement, Tawilah (Cretaceous-Paleocene) and Haraz (latest Cretaceous-Tertiary) Formations.

The age of the Aden Formation in the southern provinces was considered to be Late Miocene or Pliocene to Holocene (Greenwood and Bleackley, 1967, Beydoun and Greenwood, 1968). Radiometric dating of basaltic rock samples collected from the three volcanic fields in the northern provinces gave the following ages (Al-Jaiiani, personal communications):

- Sana'a-Amran Field: the age ranges between  $3.37 \pm 0.17$ , and  $0.17 \pm 0.47$  Ma (i.e. Pliocene-Pleistocene).
- Marib-Sirwah Field: the age ranges between  $1.90 \pm 0.21$ , and  $0.190 \pm 0.06$  Ma (i.e. latest Pliocene-Pleistocene).
- Dhamar-Rida' Field: the age ranges between  $6.53 \pm 0.33$  and  $0.0040 \pm 0.0065$  Ma (i.e. latest Miocene-Holocene).

These ranges indicate that the age of the Aden Formation in the northern provinces extends from the latest Miocene to the Holocene, and this agrees well with its age assignment in the southern provinces. The Holocene upper range age of the Aden Formation is substantiated by the fact that some of the basaltic sheets were extruded during historic times (Grolier and Overstreet, 1978) and, most of its volcanoes retain their original shape, have fresh appearance, and some are from historic time; e.g. north of Sana'a (Geukens, 1966). Furthermore, the volcano of Jabal Alisi which lies in the Dhamar-Rida' Field still emits hot sulfurous vapor.

#### Bura' Formation:

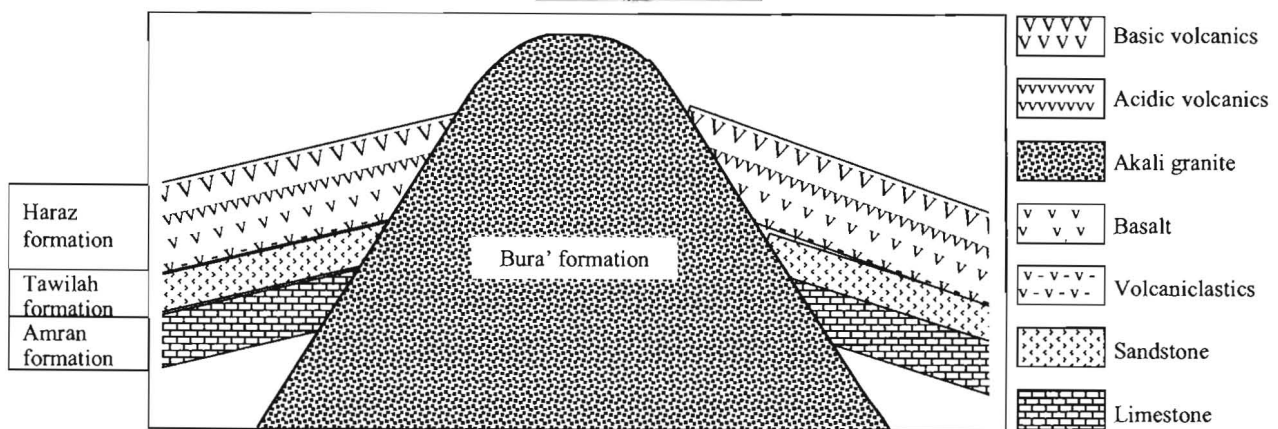
This new unit is introduced to include the post-tectonic alkaline granite of Tertiary age in Yemen (Table 1). Its type area lies in the western mountainous region in the northern provinces. The granitic body which constitutes Jabal Bura' is designated as the stratotype. Jabal Bura' (lat.  $14^{\circ} 53' 54''$  N, long.  $43^{\circ} 28' 53''$  E) lies about 48 km east-northeast of Hudaydah City (see, Fig. 1). Usually, it occurs as subvolcanic plugs, stocks and plutons. In its type section as well as in most parts of the type area, the Bura' Formation consists of alkali granite, which locally shows primary flow banding. In the central parts of Jibal Wasab (about 85 km southeast Hudaydah, lat.  $14^{\circ} 25'$  N, long.  $43^{\circ} 40'$  E), it consists of porphyritic granite, whereas in the

central parts of Jibal Hufash (about 80 km northeast Hudaydah, lat. 15° 20' N, long. 43° 27' E) and Jibal Milhan, (about 75 km northeast Hudaydah, lat. 15° 20' N, long. 43° 20' E), it consists of granite and syenite. Some granitic plutons as at Jabal Sabir (about 3 km south Ta'iz, lat. 13° 40' N, long. 44° 07' E) have syenite margins. In the southern provinces the Bura' Formation occurs in two localities, namely, Jabal Manif ( lat. 13° 17' N, long. 44° 51' E) and north-northeast of Mukayras ( lat. 13° 56' N, long. 45° 41' E). It consists of aegirine-riebeckite granite (Greenwood and Bleackley, 1967, and Beydoun and Greenwood, 1968).

In the type area, the granite is intruded through several rock units such as the Affar Sandstone (Early Jurassic), Amran Limestone (Middle-Late Jurassic), Tawilah Sandstone (Cretaceous-Paleocene), and Haraz Formation (latest

Cretaceous-Tertiary), (Fig. 5). These rocks are not affected by contact metamorphism except over a very thin interval. In the southern provinces, it was intruded through the Cretaceous Tawilah sandstones, and the latest Cretaceous-Tertiary volcanics of the Haraz Formation.

On the basis of its stratigraphical position the Bura' Formation was dated as Tertiary, probably Oligocene? to Miocene (Kruck 1984, Kruck and others 1984). A K-Ar age of  $22.7 \pm 0.9$  Ma was reported by Grolier and Overstreet (1978). This age places the present unit into the Aquitanian (earliest Miocene). Recently, Kruck and Schäffer (1991), assigned the granite of the Bura' Formation to the Oligocene-Miocene. In the southern provinces, Greenwood and Bleackley (1967) dated it as probable later Tertiary, whereas Beydoun and Greenwood (1968) assigned it to the late Cretaceous-Tertiary, probably Tertiary.



**Fig. 5** Lithostratigraphic columnar section of the Bura' Formation at its type locality (Jabal Bura').

#### Remarks:

Major exposures of the Bura' Formation lie in the western mountainous region of Yemen along the contact with the Tihamah Plain. The exposures extend parallel to the Red Sea and they are almost restricted to the graben zone. This distribution may indicate that the development of the granitic bodies of the Bura' Formation is connected with the Red Sea rifting.

#### Summary and Conclusions

The revision of the stratigraphy of the Cenozoic igneous rocks in Yemen, has led to the following conclusions:

- 1) The Cenozoic igneous rocks in Yemen consist of extrusive and intrusive rocks, with interlayered sediments.
- 2) These rocks are included within the Manakhah

Group (latest Cretaceous-Holocene) which is subdivided into three formations as follows:

- a) Haraz Formation: includes the volcanics and the interlayered sediments, of latest Cretaceous-Tertiary age.
  - b) Aden Formation: consists of volcanics of late Tertiary-Holocene age.
  - c) Bura' Formation: includes the Tertiary alkaline granites.
- 3) The Manakhah Group, Haraz and Bura' Formations are introduced as new units, whereas the Aden Formation is a readaptation of the Aden Volcanic Series of Blanford (1869).
  - 4) The Haraz Formation replaces the informal names Trap Series of Geukens (1960, 1966), and Yemen Volcanics of Grolier and Overstreet (1978) in the northern provinces, and Aden Trap Series of Greenwood and Bleackley (1967) in the southern provinces.

- 5) Considerable igneous activity predominated in the western parts of Yemen. During the latest Cretaceous-early Tertiary, extrusion of minor basaltic lava flows of the Haraz Formation is suggested to have begun in conjunction with the fracturing and rifting of the Gulf of Aden-Red Sea grabens.
- 6) During the Oligocene-Miocene time, the igneous activity reached its acme when the main bulk of the volcanics of the Haraz Formation were extended, and the alkali granitic plutons of the Bura' Formation were injected.
- 7) The igneous activity was culminated with the eruption of the volcanics and cinder cones of the Aden Formation (latest Miocene-Holocene).
- 8) The period of igneous activity in Yemen was in the form of intermittent phases and included numerous quiet intervals some of which were of long duration, so that paleosols, lacustrine, alluvial, and fluvioeolian sediments were formed and accumulated.

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