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# The geology of the northern tip of the Arabian–Nubian Shield

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ABSTRACT

Recently, a detailed (1:50,000) geological map of the Elat area, southern Israel was published. Attached to this map is a stratigraphic table of the Neoproterozoic metamorphic–magmatic complex of the study area. The Neoproterozoic basement in the Elat area encapsulates the Arabian Nubian Shield (ANS) geologic evolution. Uranium–Lead and Lead–Lead zircon ages, included in previous studies and referred to in this paper, reveal that these rocks were formed during more than 300 million years of Neoproterozoic time. The major process controlling the formation of the ANS as part of the East African Orogen is the closure of the Mozambique Ocean. The first orogenic phase in the Elat area, represented by the metamorphic rocks, includes the development of an island arc, erosion of the islands and deposition, and metamorphism. This event took place between ~950 Ma and 780–790 Ma. Elat Schist, the oldest metamorphic rock in the area, was deformed and then intruded by quartz dioritic and granitic plutons that were later deformed and metamorphosed. The amphibolite metamorphic rock facies indicate metamorphic conditions of up to 650 °C and between 4 and 5 kbar. The peak of the metamorphic event was most probably before 750 Ma. A gradual change from compressional to extensional stress regime is evidenced by emplacement andesitic magnesium-rich dykes dated to 705 Ma that were later metamorphosed to schistose dykes at a greenschist metamorphic facies. The second orogenic phase (terrane amalgamation, main shaping of crust) was associated with the emplacement of large volumes (>50% of area) of calc-alkaline intrusions in a post-collision setting. These very last stages of metamorphism and deformation are characterized by intrusion of ~630 Ma granitoids exhibiting some foliation. Pluton emplacement continued also after the end of deformation. Exhumation and transition to an extensional regime is recorded by the intrusion of shallow alkaline granites in ~608 Ma which were accompanied in ~609 Ma by rhyolite, andesite and composite dykes. The last magmatic event in the Elat area is represented by the volcano-conglomeratic series comprising rhyolites, basalts, andesites, hypabyssal intrusions of monzonite and syenite and conglomerates. The conglomerates, dated to about 590 Ma, are the products of a major erosion phase in which about 12,000 m of the section were removed. These conglomerates were intruded by 585 Ma rhyolite, andesite and composite dykes. The Neoproterozoic basement is truncated by a peneplain whose age, post 532 Ma, is constrained by the age of the youngest eroded dolerite dykes. This Early Cambrian peneplain was associated with erosion of 2000 m of the section and by chemical weathering. Three major breaks in Neoproterozoic magmatic activity are recognized: the first, occurred in Cryogenian time, lasted ~60 million years after the amphibolite facies metamorphism and before emplacement of the calc alkaline plutons, separating the first and the second orogenic phases; the second break between the orogenic and the extensional phases occurred in early Ediacaran time, encompassed ~20 million years between the emplacement of the calc-alkaline and alkaline plutonic rocks and rhyolite, andesite and the composite dykes; and the third, ~50 Ma break, occurred between the emplacement of the last felsic intrusions at ~585 Ma and intrusion of the dolerite dykes in 532 Ma, before the Early Cambrian peneplain developed.

The great lateral extension of the Cambrian to Eocene sedimentary rocks and their slow facies and thickness changes suggest a stable flat platform area at the northern tip of the ANS. Early Cambrian sedimentation began with fluviatile subarkoses of the Amudei Shlomo Formation. It was overlain by an Early to Middle Cambrian transgressive–regressive lagoonal cycle of dolostones, sandstones, and siltstones of the Timna Formation. Then Middle Cambrian subarkoses and siltstones of the Shehoret Formation and

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the quartz arenite of the Netafim Formation were deposited in a coastal, intertidal environment representing the southern transgression of a Cambrian ocean.



## 1. Introduction

The Elat area, representing a detailed story of the Neoproterozoic evolution from an island arc setting through a post collisional setting to exhumation and stabilization of the craton, contributes to the understanding of the major tectonic, metamorphic and magmatic events that led to the formation of the EAO and ANS during this time.

Three major processes controlled the geological and geomorphological evolution of the Elat area: (1) formation of the Arabian–Nubian Shield (ANS) during the Neoproterozoic, as part of the East African Orogen (EAO), related to the closure of the Mozambique Ocean; (2) accumulation of a Cambrian to Eocene sedimentary sequence at the south margins of a Cambrian and Neo-Tethys oceans; and (3) the Miocene to recent evolution of the Dead Sea Transform (DST), a sinistral fault zone, which is the present plate boundary between the Arabian Plate to the east and the African Plate–Sinai Microplate to the west.

The well-exposed stratigraphy and structure of the rocks, due to the extreme arid desert climate of the Elat area, document these three processes. This study was done in the framework of the geological mapping of the Elat area as part of the 1: 50,000 scale geological mapping project of the Geological Survey of Israel. This map is based on previous maps (Shaw, 1947; Picard, 1943; Bentor and Vroman, 1955; Garfunkel, 1970; Druckman et al., 1993, among others) and was updated by field work during the present study. This present effort to achieve a very detailed map was carried out on a 1:10,000 average scale using GIS and orthophoto map as the base map (Fig. 1). The map is available in the Geological Survey of Israel web-site http://www.gsi.gov.il/_Uploads/1767Elat.html.

## 2. Geomorphology

The landscape of the region is controlled by the regional Neogene uplift and development of the DST and basins associated with it. The Neoproterozoic metamorphic–magmatic rocks are exposed in the Roded and Elat blocks to the southeast and in the Amram Block in the north (Fig. 1). The eastern part of the Elat Sheet comprises young structural basins, more than 1000 m deep, in the southern Wadi Arava developed along the western margins of the DST (e.g. Frieslander, 2000) and in the Gulf of Aqaba/Elat with a water depth of up to 1500 m (e.g. Sade et al., 2008), which are underlain by several kilometers of young sediments. The geomorphological land expressions of these basins in the map area are the Avrona playa, the Elat sabkha and the alluvial fans of the ephemeral wadis draining eastward into the southern Arava and the gulf. Most of these wadis incise the sedimentary rocks of the grabens on the western side of the map area and the metamorphic–magmatic blocks on the east. The topographic elevation in the west ranges from 700 m to more than 800 m whereas in the east they range from sea level to +40 m in the playa. This sharp difference in relief in an east–west direction within less than 15 km is the major reason for the canyon morphology of the wadis, and the excellent Neoproterozoic outcrops in the map area (Fig. 2). East of the map area, in southern Jordan, the highest topographic elevation are between 1.400 and 1.600 m. The high topographic elevation on both sides of the Dead Sea rift resulted from a regional uplift beginning at Late-Oligocene–Early Miocene (Avni et al., 2012).

## 3. Stratigraphy

The Elat area comprises three major rock sequences: (1) the Neoproterozoic, mainly metamorphic–magmatic basement; (2) the Cambrian to Eocene sedimentary rocks and (3) the young clastic rocks deposited during the evolution of the DST since the Miocene. The Early Cambrian peneplain (Beyth and Heimann, 1999) a regional planar erosion surface, with some relief in the map area, separates the first two sequences whereas the Oligocene erosion surface separates the second and third sequences (Avni et al., 2012). This paper deals with the Neoproterozoic metamorphic–magmatic basement and the Cambrian Yam Suf Group directly overlying it at the northern tip of the ANS.

### 3.1. The Neoproterozoic rocks

The metamorphic–magmatic rocks (Bentor, 1961;Garfunkel, 1980, Fig. 3) of the Elat, Roded and Amram blocks were mapped as part of the northern margins of the ANS. These rocks formed, as part of the Neoproterozoic crustal evolution, during more than 300 million years (Be'eri-Shlevin et al., 2009a,b,c; Kolodner, 2007; Kroner et al., 1990; Morag et al., 2011a,b). The oldest rocks mapped are at the Roded and Elat blocks and the youngest was at Mt. Amram. This basement complex developed in three orogenic cycles: the first an island arc one; the second a post collisional one; whereas the third late orogenic one represent exhumation, deposition of sediments in local basins, and stabilization of the region. U–Pb dating of single detrital zircons from the post orogenic Elat Conglomerate reveals that the upper crustal rocks were formed mainly in two major magmatic cycles (Morag et al., 2012): the island arc magmatism peaked at ~800 Ma; and the voluminous post-collisional granitoids that intruded the amalgamated arc crust in the second orogenic phase and peaked at 610–630 Ma. Results of the Sr, Nd and Hf isotopic analysis are in line with an overall juvenile character of the ANS, with some contamination of older crust (Steinitz et al., 2009; Be'eri-Shlevin et al., 2009a,b,c; Morag et al., 2012).

#### 3.1.1. The first orogenic phase

This phase is represented by the **metamorphic rocks**. The oldest rocks in the Elat block consist of the metapelitic and metapsammitic Elat Schist, deposited ca. 800–813 Ma ago (Kroner et al., 1990; Eyal et al., 1991). Detrital zircons with no overgrowth from the schist reveal crystallization age of up to ca. 950 Ma (Morag et al., 2011a) proving that the magmatic island arc, from which the protolith of the schists was derived, formed from that time at least. The main metamorphic minerals comprising the schist are biotite, garnet, staurolite, cordierite, andalusite and silimanite (Shimron, 1972). This mineralogic association suggests temperatures of 580–660 °C and pressures from 4.6 to 3.8 kbar (Matthews et al., 1989; Vapnik, 1993). The Elat Schist is intruded by the Taba quartz-diorite gneiss, 782–790 Ma (Morag et al., 2011a; Kroner et al., 1990) and by the Elat Granitic Gneiss, 740–744 Ma (Kolodner, 2007; Kroner et al., 1990).

The oldest metamorphic rocks of the Roded block, the Roded Migmatite and Roded Schist 800 Ma old (Morag et al., 2011a) are similar to the Elat schist and formed under amphibolite facies suggesting temperatures up to 650 °C and pressure from 4 to 5 kbar. The peak of the metamorphic event was probably pre-750 Ma (Katz et al., 1998).

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