GEOLOGICAL EXPLORATION AND PRODUCTION OF THE BERENICE MARBLE FROM DARNAH FORMATION (BARTONIAN TO PRIABONIAN), AL JABAL AL AKHDAR, NE LIBYA

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Abstract: The title Berenice (the historical name for Benghazi city) marble is coined by the project's owner, who has the right to exploit the quarry. The excavation of stone blocks from the Darnah Formation's crystalline and durable limestones is one of the most important operations in this paperwork. The study's objectives are to focus on various parts of geology and their importance in enhancing national economic development. Also, pay attention to the rocks' geological properties in order to determine their suitability for marble production and future potential as building stones. The geology of the research area is dominated by Tertiary system successions, which include three major carbonate sedimentary rock formations. Darnah (Middle to Upper Eocene), Al Bayda (Lower Oligocene), and Wadi Al Qattarah (Upper Miocene) of the Ar Rajmah Group. The Darnah Middle Eocene Gizehensis bed contains potentially massive marble productive formation for building stone as in-situ accumulations of large benthic foraminifers of nummulites (Nummulitic bank), which are considered to be good indicators of shallow marine carbonate environments in fossil series. Where the strong and durable stone has been carefully selected, the Darnah Formation is reduced to size and used as slabs, blocks, and columns. Even if output is doubled, this quarry's stockpile is sufficient to last hundreds of years.

Keywords: Darnah Formation, Benghazi, durable limestones, Eocene, Gizehensis.

INTRODUCTION

Al Jabal Al Akhdar has produced a one rock types for building stone that include limestone, which is can be product of more than 10 types of limestone, marble, travertine (travertine is deposited from the water of mineral springs and it is usually used in the form of tiles for wall cladding and flooring) and other decorative stones with different textures, colors and patterns. The Darnah Formation has a wide range of applications in the construction due to their durability and the fact that they can be easily polished. Large benthonic foraminifera *Gizehensis*rich accumulations very common in this formation and can be easily observed in polished sections. In industrial raw materials, the limestone is classified as a low-value commodity because it's wide availability. In general, we do important discussing with the owner to know what type of marble is required and then we start making our geological study to choose the most appropriate places in terms of quality and quantity as well as the closest to its factory taken into account the factor of transportation. This area of study has been explored, selected very carefully and opened as a marble quarry because of its specifications are very close to the marble required and also it has a lateral and vertical extent. Berenice is the ancient name of Benghazi city, NE Libya; the term is defined by the Italian colonization (1911-1942) in World War II.

Location of the quarry

The study area is located in the northwestern part of Al Jabal Al Akhdar (Fig. 1), about 45 km NE of Benghazi city. Bounded by the latitudes of (32° 23'6'' to 32° 25' 30'' N) and longitudes of (20° 31' 30", 20° 37' 60" E).

Objectives

The importance of geologists in contributing to the development of the national economy. And to

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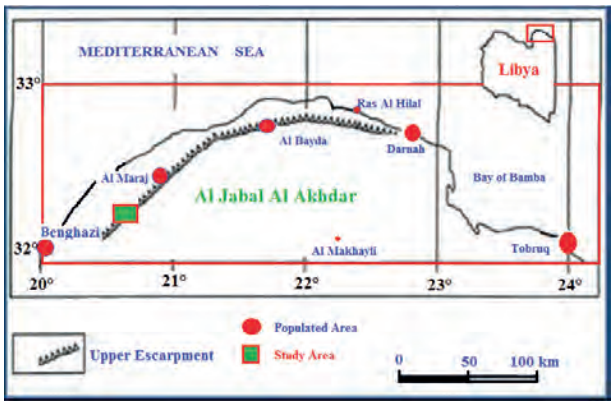

Fig. 1. A map showing the location of the study area.

find out alternative sources of the imported marble from abroad. This kind of limestone raw material of sedimentary rocks of the Darnah Formation is classified as low commodity value (because of its wide availability and cheap). Transport costs are a significant and dominant component of the price paid by customers.

MATERIALS AND METHODS

***Perforator Drilling Machine*:** A perforator drilling machine is used for prepare the vertical and horizontal drillholes the diameter of 76mm (Fig. 2). The vertical and horizontal drill holes must have the same direction to allow easy connection of thediamond wire saw. The diamonds wires saws machines which in use are: Telediam type 45-55S from the Pellegrinicompany, Marini mini fill, Diamond board and Alfa 840 from Benetti machines company (Italy).

Diamond Wire Saw Machine: The use of a diamond wire saw cutting machines in extraction, exploitation of the commercial blocks (dimension stone) in very specific operations (Fig. 3).

Stratigraphy

Al Jabal Al Akhdar anticlinorium lies in the northeast of Libya, in a province known as Cyrenaica. It was developed at the southern margin of the Mediterranean geosyncline of the Tethys, on an attenuated continental crust of the north passive margin of the Afro-Arabian shield (El Hawat*et al*, 2004; El Hawat and Shelmani, 1993). The rocks of Al Jabal Al Akhdar are mainly of marine carbonate sedimentary units ranging in age from Late Cretaceous to Late Miocene (Fig. 4). The geology of the area is mainly represented by successions carbonate sedimentary rocks of Paleogene-Neogene formations ranging in age from Middle to Upper Eocene to Upper Miocene. The stratigraphic sequences comprise of three formations from oldest to youngest; Darnah Formation which consists of nummulitic limestones; Lower Oligocene; Shahhat Marl and algal limestone members of Al Bayda Formation (Fig. 5); and Middle Miocene Wadi Al Qattarah Formation composed of oolitic limestone of the ArRajmah Group. The total thickness of the exposed section is about 100 meters. Wadi Al Qattarah Formation is observed

Fig. 2. The perforator drilling machine type for preparing drill holes for cutting the rock into commercial blocks using diamond wire.

Fig. 3. Lateral cutting of a primary block with a diamond wire, a Libyan diamond wire saw machine. A) shows the beginning of cutting of the commercial block; B) the final stage of block separation.

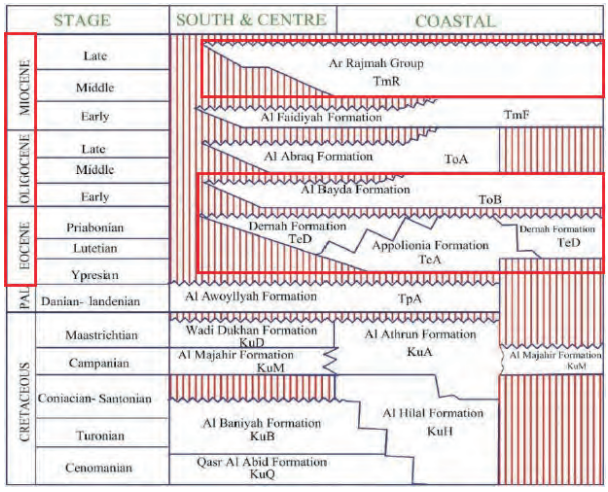

Fig. 4. Stratigraphical chart of northern Cyrenaica (Modified after El Hawat *et al*, 2004; El Hawat and Shelmani, 1993; also see Muftah *et al*, 2017 and Sheltami *et al*, 2018).

Fig. 5. Showing two different formations are well exposed in the first escarpment.

at a higher elevation and not clearly noticed in the first escarpment. These formations are separated by erosional or non-depositional surfaces.

Darnah Formation (Middle-Upper Eocene)

The term Derna (Darnah) was introduced by Gregory (1911) and showed the Apollonia Limestone to be overlain by the Derna. The carbonate sequence conformable overlying the Apollonia and disconformably underlying the Al Bayda Formation represents the Darnah Formation (Klen, 1974; Zert, 1974). Toward the south, the Darnah Formation decreases in thickness gradually and completely wedges out on the Southern part of Al Jabal Al Akhdar (Rohlich, 1974). In general, Darnah Formation represents the high-energy rim-margin facies, with reefal limestones, corals, nummulites, and algae, and was defined near Darnah where 330 ft (100.584m) are exposed. The age ranges from Bartonian to Priabonian so it is a partial age equivalent of the Apollonia Formation (Hallett and Clark-Lowes, 2016; Hallett, 2002; Sheltami, *et al*, 2018). These rock units of Darnah Formation in the study area are well defined with exposed thickness reaches (60m) and the productive beds with a total thickness of 25m as illustrated at benches 1, 2 & 3 (Fig. 6). The in situ carbonate production of *Nummulites Gizehensis* very thick bed of Middle Eocene Darnah Formation in particularly at the area is recorded and considered to be good indicators of shallow marine carbonate environments in fossil series (Figs. 7A & 7B). The highly porous Nummulitic banks (bench 2; increased in B-Form, Fig. 8), brown in color and acted as an effective barrier and the microstructure in nummulites grains is clearly observed it may due to the highly action current of the storm wave base (El Hawat*et al*, 2007), invasion by carbonate mud took place later and completely filled these fractures (Fig. 9), producing back-bank (bench 3), dark brown, grainstone, crystallized with less porous of calcitic dolomite-rich in *Nummulites Gizehensis* and fore-bank (bench 1), white to yellowish in color, wackestone with less nummulites contents.

In general, the Nummulitic bank of the Eocene sedimentary rocks have attracted the attention of many workers such as: El Hawat*et al*, 2007; Muftah *et al*, 2017, Aly et al., 2001, Abu El Ghar and Hussein, 2005, Papazzoni, 2008, Tawfik *et al*, 2016, Rafi *et al*, 2012,Al-Bloushi and Tanoli, 2018, Sallam*et al*, 2014, Schaub, 1981, Racey, 1995, Imam, 1999, and Megrisi and Mamgain, 1980.

Darnah Formation with Building Stone Potential

The depositional environment, mineralogy and cementing material are all helpful to determine the suitability of Darnah Formation for use in building stone where the strong and durable stone has been correctly selected. That's why is typically quarried at a different level in rectangular commercial blocks then sawed and finished to specified sizes. The blocks in Darnah Formation yield three types of commercial blocks are represented in benches (benches in the open pit are 4-6m high), whereas,

Fig. 6. Showing cut benches of Darnah Formation (looking, NE).

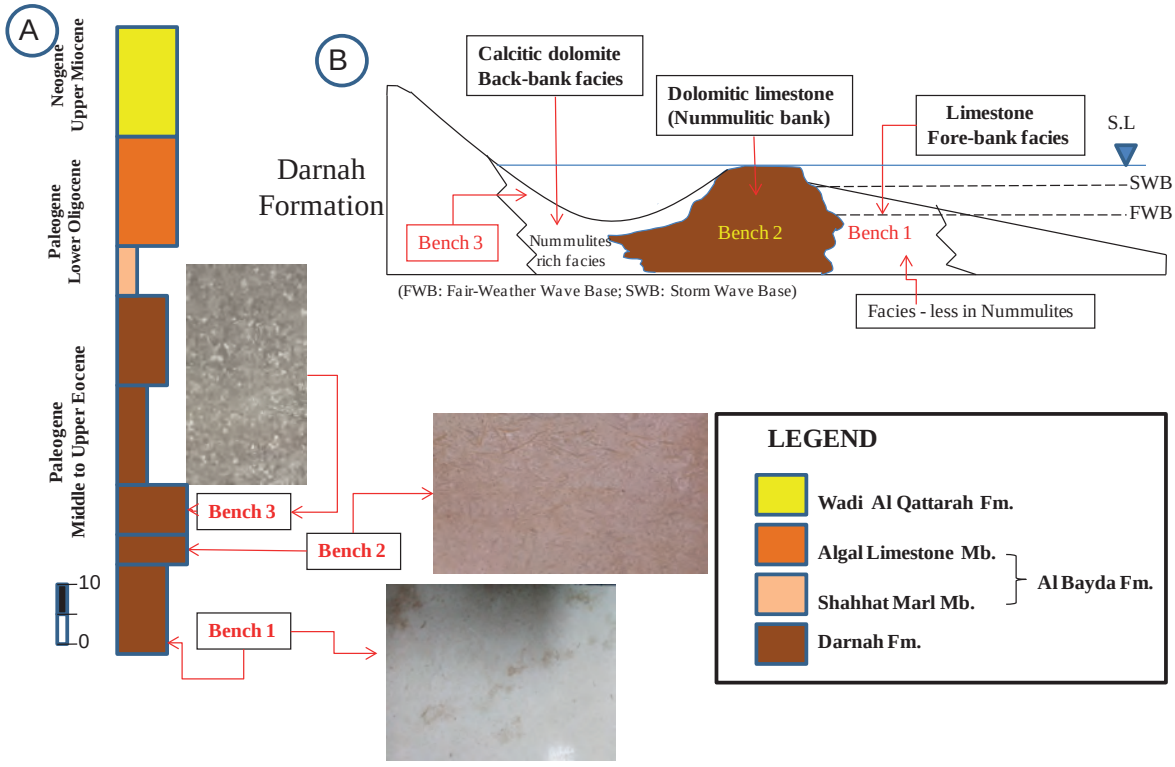

Fig. 7. A) successions carbonate sedimentary rocks of Paleogene-Neogene formations and the productive beds of Darnah Formation as illustrated at benches 1, 2 & 3; B) simple scheme of the depositional environment.

bench 4 is a durable conglomerate of Quaternary deposits constitute alluvial terraces and cover the wadi floor (Fig. 10).

The blocks are cut into two sizes with total weigh are ranging from 4 to 6 tones; small one of about 1m x 2m x 2.5m in size and the large block with 2m x 3m x 2m in size and the blocks weigh of up to 4-6 tones can be obtained.That can be produced from a cleaned benches which contain a volume of full annual production of 2000m^3 of marble blocks and the number can be increased and that depends on the number of machines and labor availabilities. The marble will be mined by isolating from the main rock mass and then cutting it into blocks with an arm sawing machine and diamond wire saws to minimize the possibility of the propagation of cracks formed by blasting into the marble. Natural fractures and joints can be a negative factor influence the design of the extraction area and limit the block size that can be produced (Fig. 11). When quarrying stone for building purposes, it is always preferable to extract the largest blocks because larger blocks allow for greater variety in usage. Larger blocks are more difficult to obtain because of the jointing and bedding plane directions and impurities that could cause the rock to crack in undesired places. However, joints at regular intervals can be also a positive factor for building stones because they can aid in extraction and give regular stone

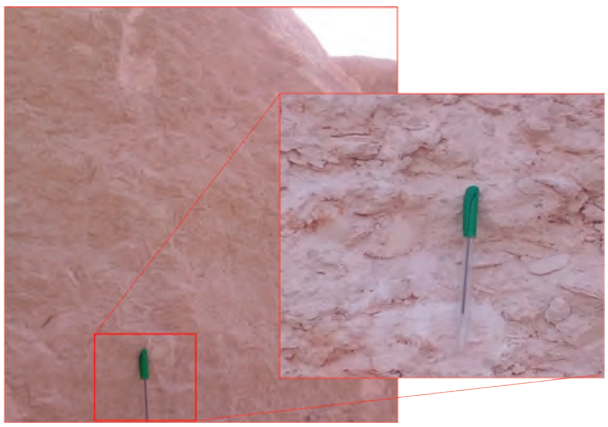

Fig. 8. Nummulitic bank of Darnah Formation (bench 2).

Fig. 9. A polished limestone of the uppermost the productive beds of bench (1) Nummulites shells are clearly affected by storm wave base (SWB) action.

Fig. 10. A polished conglomerate of Quaternary deposits (bench 4).

Fig. 11. Natural fractures and joints in the productive units of Darnah Formation.

thicknesses. Some of these joints are completely filled with 3 stages of calcite overgrowth and banded colors due to contamination (Fig. 12). The inclusions resulting of usually a chalky limestone that has been incorporated in the rock of Darnah Formation during deposition affect the quality of the finished surface of the stone and therefore, it is undesired to the buyer in the architecture or landscaping market. The commercial blocks are extracted and moved by fork loaders on the trucks and loaded into the main factory (Fig. 13). The waste is dumped into the landfill close to the open pit. Generally, the price of the larger blocks is proportionately higher, since it is difficult to obtain them intact. After the cutting process, the smaller pieces can be obtained, which are treated and sold for different uses.

The blocks obtained at the quarry blocks are sent to factories for the manufacturing of the finished products that are used in building sites. The block is delivered at the factory and cut into thin layers called slabs or boards. These are typically 2-3cm thick, but any thickness is possible. Treatment is applied with fine grain grinds and subsequent polishing with alumina powder, or other similar products which continuously appear on the market (Fig. 14).

The boards of finished products are further divided into smaller pieces, usually on request. The most common examples are plates for cladding and paving tiles.

Applications and uses of the natural stone

Limestone and other carbonate rocks are extremely valuable raw materials are widely used throughout industry, although the construction (The primary use of carbonate rocks in construction as aggregates) and cement manufacturing industries are generally the principal consumers. Darnah Formation can be used as blocks for walls, sills for windows or archways for doors. It can also be used for decorative purposes and dimension stone. Also is covering a wide range of commercial products, which include paving tiles, flooring e.g marble staircase, veneering for cladding, masonry, slate roofs and individual cut stones. The final product is obtained by cutting up the slabs with different measures, according to demand (Fig. 15). Although the main technological function of claddings is for insulation, day by day innovations in this field appear, creating shapes from different claddings as those of the image with limestone cladding (Fig. 16).

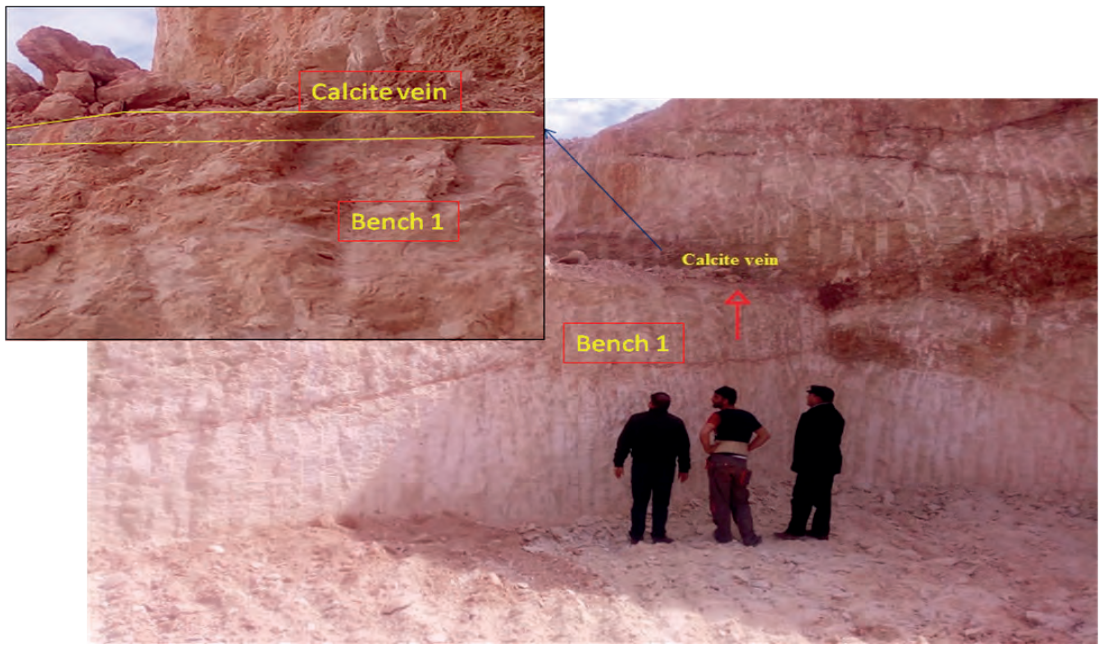

Fig. 12. Joints are parallel to the bedding plane with banded colors of calcite overgrowth (vein-like).

Fig. 13. The commercial blocks are loaded on the trucks to the main factory

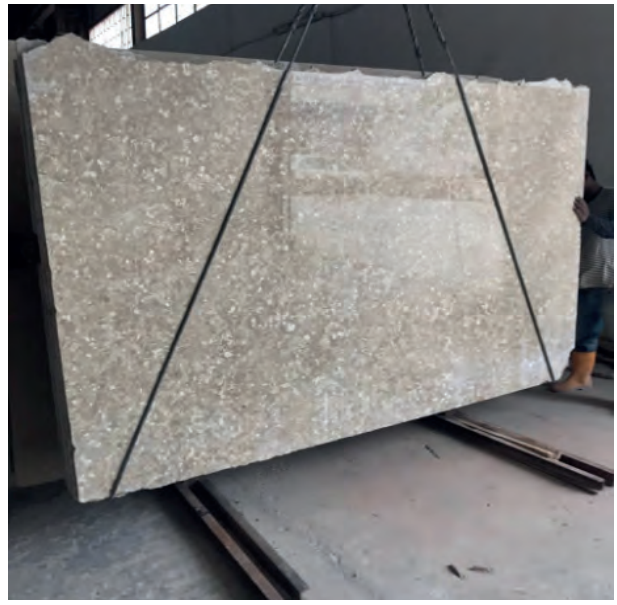

Fig. 14. The block is delivered to the factory and cut into thin layers called slabs or boards (typically 2-3 cm thick).

The significances of this paper

It helps in the elimination of unemployment and provides job opportunities for young people, the people who have trucks and loaders in the area where the quarry is located. Educate them to learn the drilling operation techniques and the use of rock cutting machines. The owner of the land is got an attractive price from renting the land annually. An annual rent is also paid to the Ministry of Industry for extraction per cubic meter and the prices are depending on the type of raw materials. Drilling water well at the site as well as benefiting from the land after completion, cleaning, and exploitation by the landowner to use for any other purposes. Economic development and increases the income of citizens through the discovery of many quarries. However, several other quarries have been discovered and selected for other limestone sedimentary rock types (Upper Cretaceous and M. Miocene in age), have very high quantity and quality compared to the Spanish, Italian and Turkish marbles and are currently under construction, where the manufacturer is currently completing administrative issues before starting in extraction processing. Parts of these blocks are

Fig. 15. Cutting up the slabs with different measures, according to demand.

Fig. 16. Shows multiple photos of marble of Darnah limestone used in buildings.

exported to Tripoli with very reasonable prices of about 20 L.D without cutting those blocks into slices. The exploitation of other marble factories where there is no continuous work for the purpose of cutting the rocks in sizes 2 and 3cm, and thus also is a benefit for the owners of these factories and help to increase their income. This type of marble was imported from abroad and in hard currency and sold to the consumers at very high prices. But after the discovery of this national marble, the prices became lower and sold of one-third of the total amount. The reserve of this quarry is enough for hundreds of years even if the production is doubled for this quarry.

CONCLUSIONS

Limestone and other carbonate rocks are extremely valuable raw materials are widely used throughout industry, although the construction. This kind of research paper is new in Libya because most of the exploitation of carbonate raw materials are concentrated only on the aggregates and its uses in road constructions, concretes, dimension stones and

cement manufacturing industries are generally the principal consumers. Darnah Formation is mainly hard limestone (sedimentary rocks), abundant and low-cost commodity.It was used only in crushed stone prepared for road construction projects. It's used now as a marble for the first time. The limestone is widely used in hallways, guest rooms, washrooms and stairs, solid slab decorations, building stones, flooring tiles, paving stones, curbing and in other decorative purposes. The hard limestone of this formation has been sold to end users as marble in terms of strength, durability, workability, abundance, appearance, abrasion resistance and weathering. Most building-stone quarries occur where the stone outcrops in a valley, escarpment or anywhere that there is minimal overburden. This place of mine has been explored, selected very carefully and opened as a marble quarry because of; 1) very close to the factory of the owner; 2) Gizehensis rich accumulations where the nummulites grains are well distributed and gives a very nice mosaic and add value to the marble slabs; 3) the absence of chert nodules or bed; 4) minimal overburden; and 5) it have lateral and vertical extents. The marble units of economic interest have been identified as a white to cream and light brown marble which is overlain by a dark brown calcitic dolomite-rich in nummulites. The mine comprises of three major benches dimension stone and the commercial blocks differ in sizes; small one about 1m x 2m x 2.5m and the largest block with dimension of 2m x 3m x 2m in size and the blocks weigh up to 4-6 tones is obtained, the full annual production of 2000m^3. In general, Al Jabal Al Akhdar has produced a one rock types for building stone that include limestone, which is can be the product of more than 10 of limestone types, marble, travertine and other decorative stones with different colors and patterns. These visual differences in colors, grain sizes, textures, and patterns can influence the buyer in the architecture or landscaping market. The limestone is mainly obtained from the middle of Darnah Formation. It is called "Berenice" the old name of Benghazi city and is characterized by its patterns and colors.

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