

# **“Pobiti kamani” (“Upright Stones”)**

## **Geopark**

(Project)

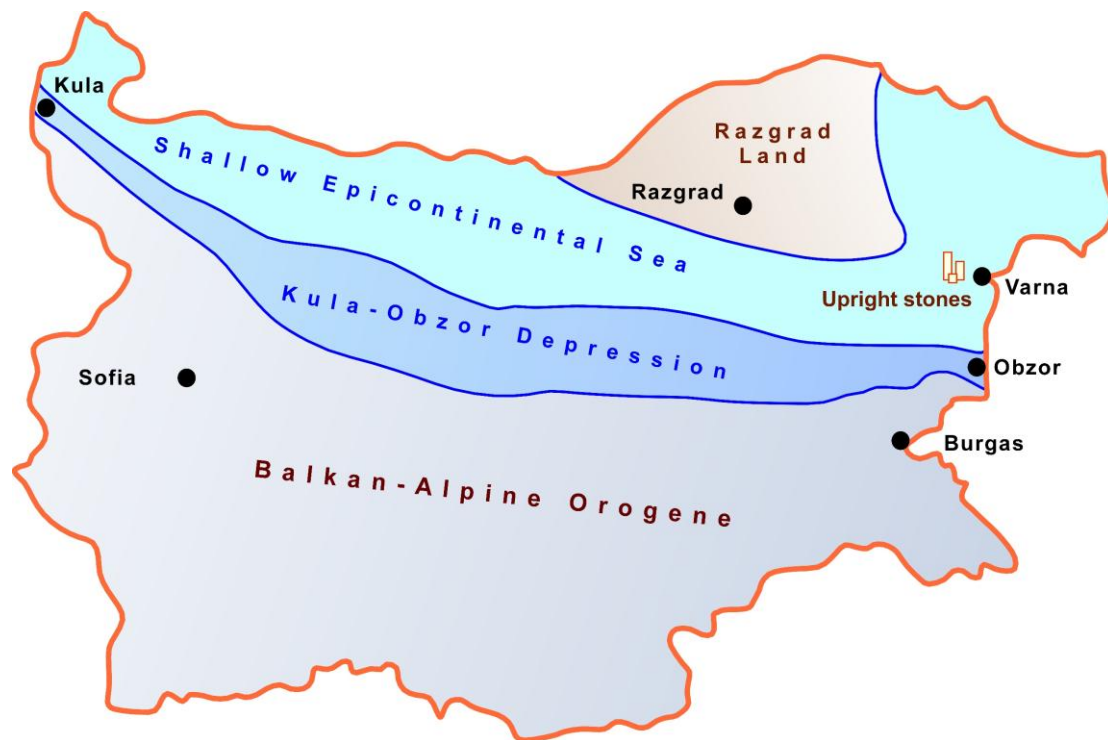
**Dimitar Sinnyovsky**



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## Introduction

The geological phenomenon “Upright Stones” (“Varna Columns”, “Varna Reefs”) is a unique natural formation that has been the subject of scientific debate for nearly 200 years. The Varna Columns, called by Prof. Ivan Nachev algal bioherms, are majestic limestone pillars of natural origin. These marine biogenic structures were formed during the Eocene epoch about 50 million years ago in a shallow tropical sea that covered the territory of Northern Bulgaria (Fig. 1). In its eastern part, sea currents have uncovered the hard carbonate bottom and created conditions for the formation of ring-shaped mini atolls. This is due to the ability of algae to form micrograinular calcite and build reefs according to the known mechanisms for reef building in nature. The vertical growth of the ring-shaped atolls is a response to the sand accumulation around them in their effort to stay afloat. In this way, the round miniatolls grew and formed columns with a carbonate outer wall and a hollow inner zone with an abundance of Eocene marine organisms (stromatolites, nummulites, discocyclina and small foraminifera). Similar current processes, which very accurately explain their formation, occur in Shark Bay in Australia.



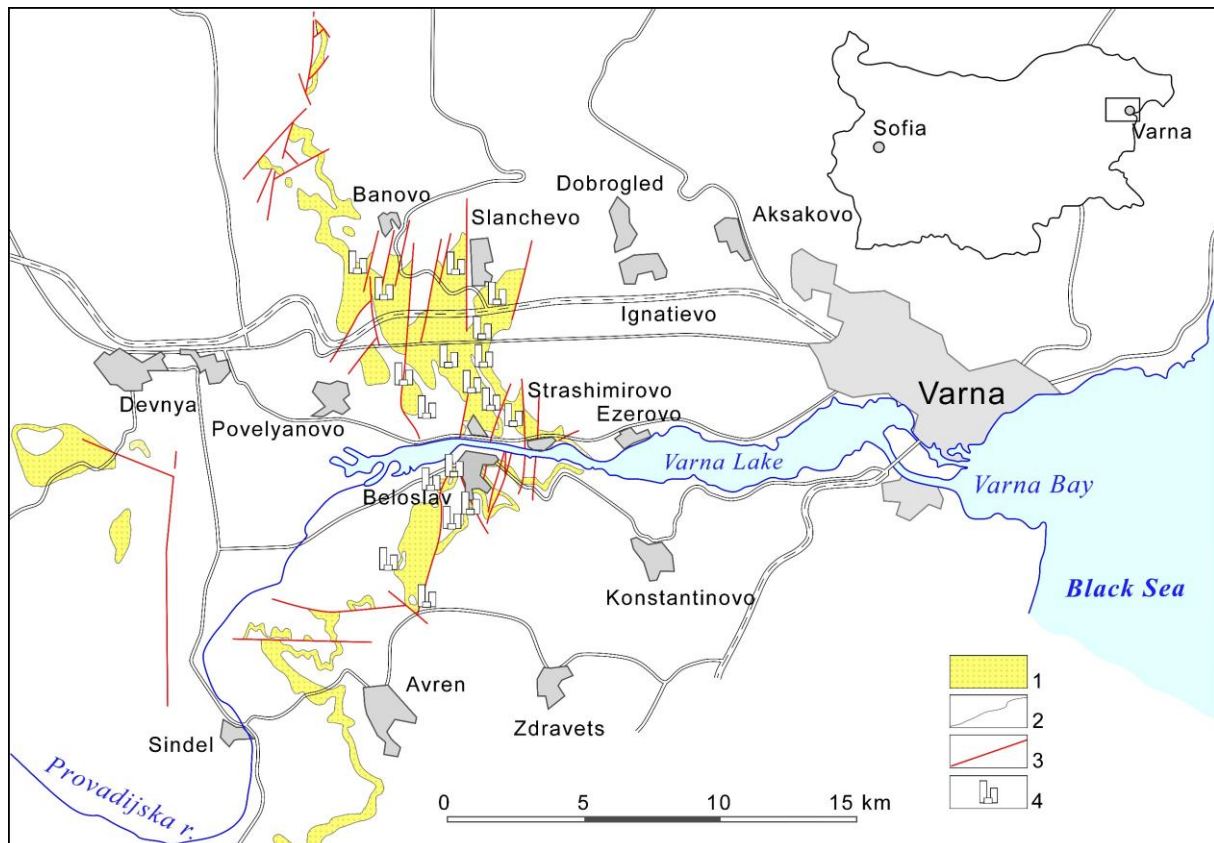
**Figure 1.** Paleogeographic setting during the Ypres Age: the “Pobiti Kamani” (“Upright Stones”) region was located in a shallow epicontinental sea, at the bottom of which there were conditions for the emergence and development of algal bioherms; NW of the region was the coastline of the Razgrad Land, and to the south was a deeper marine basin (Kula-Obzor Depression).

The “Upright Stones” are known by various names – “Dikilitash”, “Standing stones”, “Stone forest”, “Algal bioherms”, “Carbonate chimneys”, “Tubular sandstone concretions”, “Varna columns”, “Varna reefs”, etc. They are revealed in 18 geotopes (16 natural and 2 artificial) on a total area of 253 hectares, located 20 km west of Varna in the vicinity of the town of Beloslav and the villages of Strashimirovo, Slanchevo and Banovo (Fig. 2,3).

## Geological setting

Before considering the genesis of the „Pobiti Kamani“, we will focus on the geological structure of the area. Geologically, the area falls into the Varna Depression, also known as the Varna Monocline. It is

part of the Moesian Platform, representing the Post-Jurassic structural plan. The slope of the strata in the Varna Monocline is 5–10° to the east. The area is characterized by excellent outcrops and good geological knowledge. A number of faults fossilized by Quaternary deposits have been identified. The Varna Depression is composed of several Paleogene units that are exposed on the southern slope of the Varna Plateau and the northern slope of the Avren Plateau. These are the Komarevo, Beloslav, Dikilitash, Aladan and Avren Formations, belonging to the Thanetian, Ypresian and Lutetian stages of the Paleogene system, proven by nummulites (Аладжова-Хрисчева, 1990). They overlie transgressively Upper Cretaceous and Lower Cretaceous terrigenous-carbonate rocks (Fig. 4).



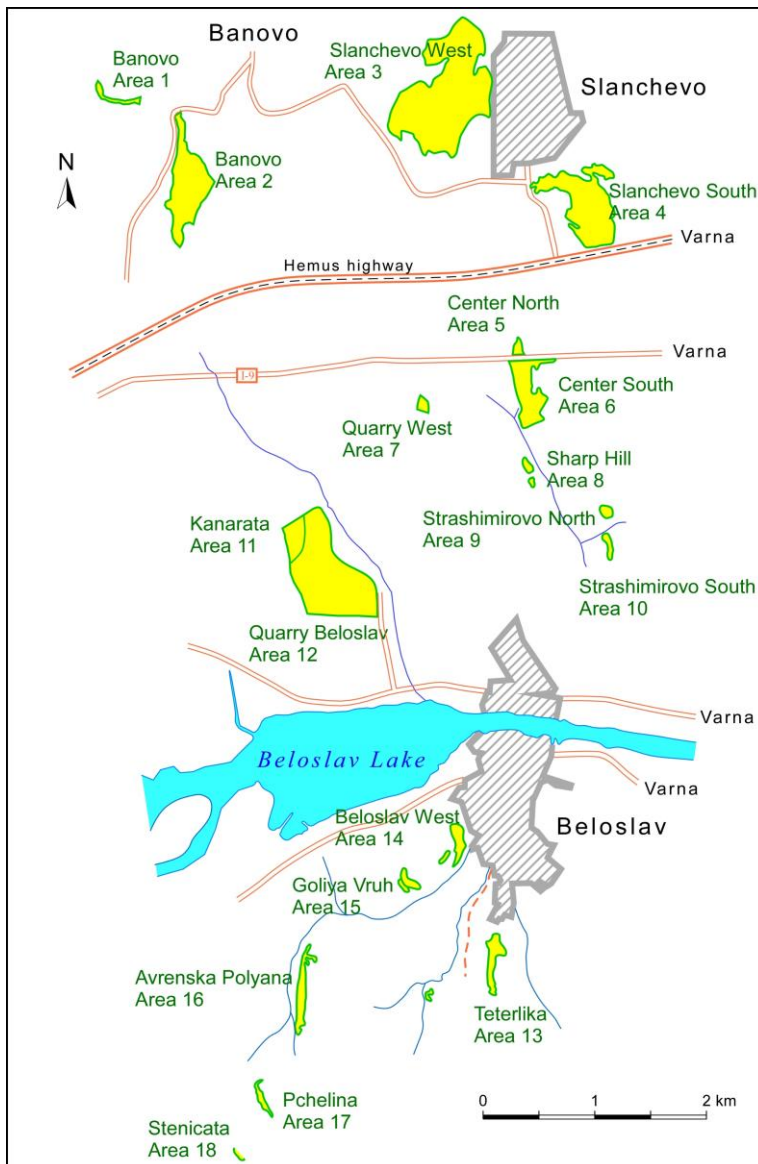
**Figure 2.** Sketch-map of the distribution of the columns and the accommodating Dikilitash sands in the Varna region: **1**, Dikilitash Formation (Eocene); **2**, Lithological boundary; **3**, Fault; **4**, Geotopes with outcrops of the Varna columns.

The Komarevo Formation (Дачев, 1975) transgressively overlies the Upper Cretaceous units of Campanian-Maastrichtian age and is overlain transgressively by the sandstones of the Beloslav Formation. It is represented by several meters of lithothamnium limestones of Middle-Late Paleocene age.

The Beloslav Formation (Аладжова-Хрисчева, 1984) is composed of yellowish clayey sandstones with interbeds of calcareous sandstones and sandy marls belonging to the Upper Ilerdian substage of the Lower Eocene. These rocks underlie the Varna Column-containing sands of the Dikilitash Formation. The lower boundary with the lithothamnium limestones of the Komarevo Formation is unconformable, and the upper boundary with the Dikilitash Formation is a transition from clayey to quartz sands. The thickness of the unit in the Avren Plateau around the town of Beloslav is 52 m, but in the Varna Plateau it is less than 25 m.

The Dikilitash Formation ("Dikilitash sands" Гочев, 1933) is composed of whitish quartz sands, siltstones and sandstones with interbeds of nummulitic limestones and algal limestones, which form

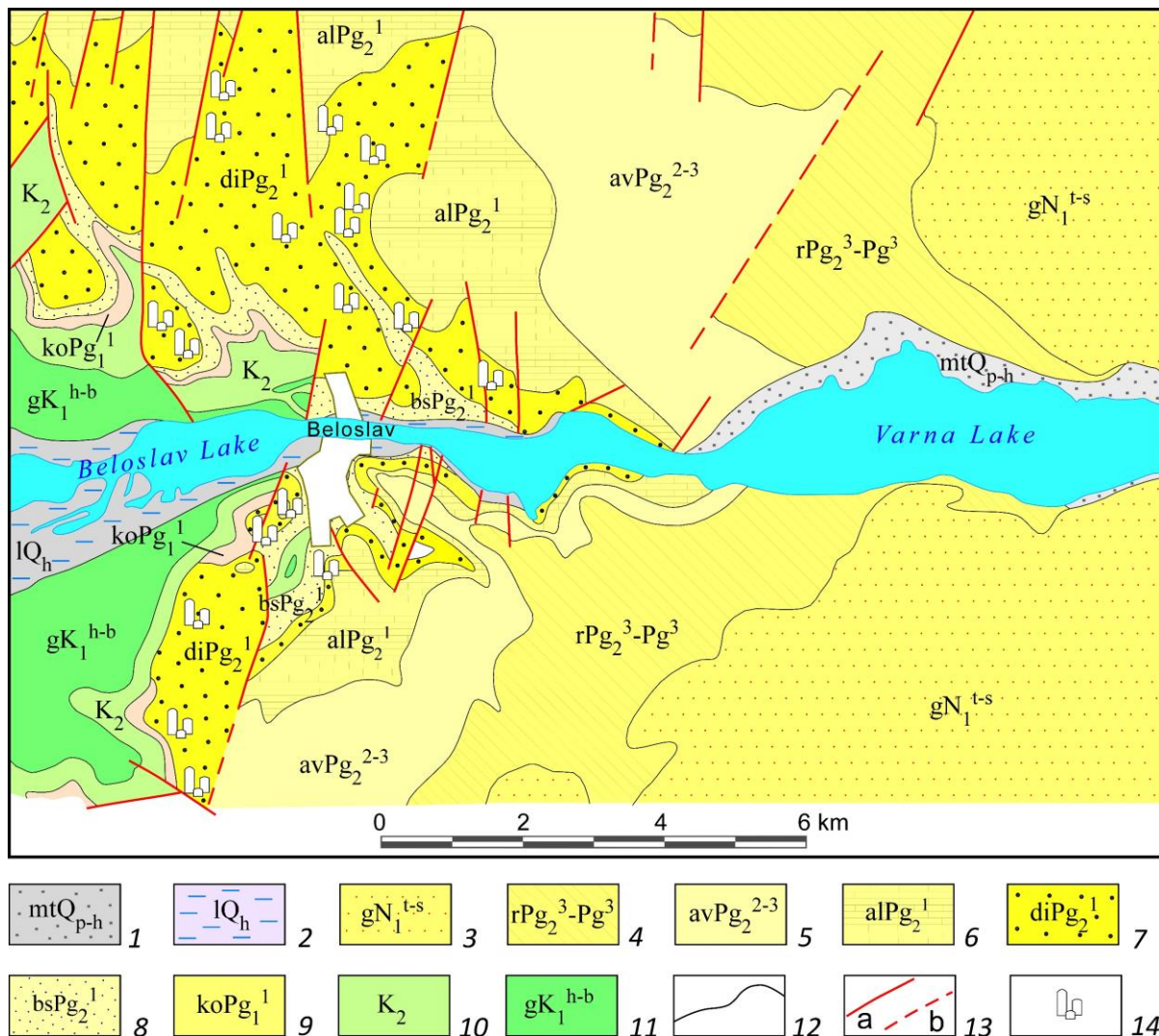
vertical columns. Aladzhoa-Hrischeva (1984) refers these deposits to the Lower-Middle Cuisian substage of the Lower Eocene. The upper boundary is a rapid lithological transition to the sandy limestones of the Aladan Formation or an abrupt lithological boundary with the marls of the Avren Formation. The fossil content is mainly of nummulitids, but annelids, bivalves and rarely cephalopods (nautilus) are also found. The lectostratotype section with a thickness of 42 m is in the southwestern part of Beloslav town. It extends widely north of the Beloslav Lake and more limitedly south of it, between the town of Beloslav and the Kamchia River. The Aladan Formation ("Aladan Limestone Horizon" Гочев, 1933) is composed of strong white bioclastic nummulitic limestones.



**Figure 3.** Sketch map of the geosites with outcrops of Varna columns

Dikilitash Formation ("Dikilitash sandstones", Гочев, 1933) is composed of whitish quartz sands, silts and siliceous sandstones with interbeds of nummulite limestones and algal limestones that form vertical columns ("Upright Stones"). Аладжова-Хрисчева (1984) referred these deposits to the Lower-Middle Cuisian Substage of the Lower Eocene. The upper boundary is a fast lithological transition to the sandy limestones of the Aladan Formation or sharp lithological boundary with the marls of the Avren Formation. The fossil content is mainly of nummulites but also annelids, bivalves and rare cephalopods (nautilus) are also encountered. Lectostratotype with a thickness of 42 m is in the SW end

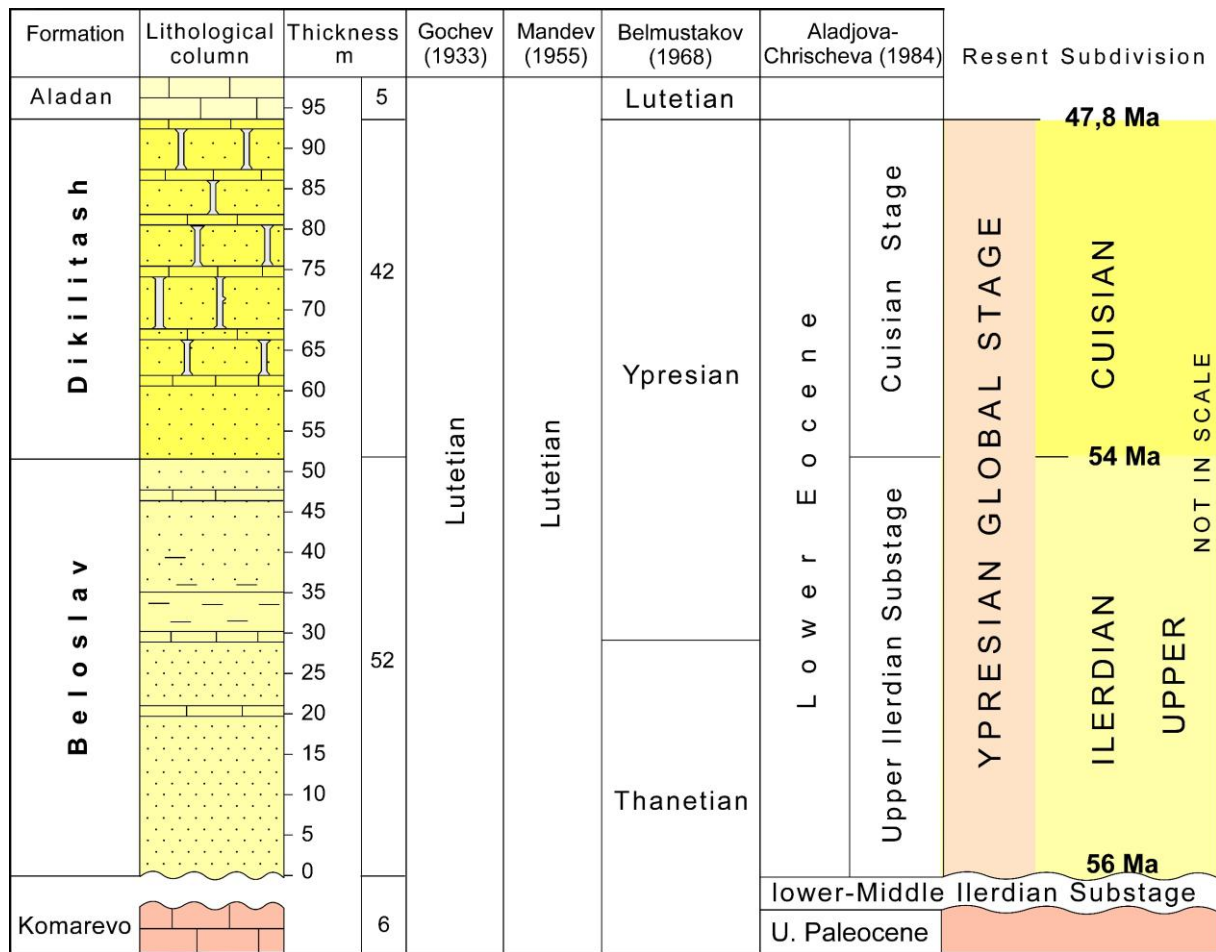
of Beloslav town. Dikilitash Formation crops out widely north of Beloslav Lake and more restricted south of it, between Beloslav town and Kamchia River.



**Figure 4.** Geological map of the area at a scale 1:100 000 (after [Cheuumev et al., 1992](#) with additional data): 1 – recent marine formations (Nimphean and Novochernomorlian terraces) (Holocene): beach sands and peat; 2 – lacustrine-swamp deposits (Holocene): sands, clays, peat; 3 – Galata Formation (Tarchanian-Sarmatian): sands with clayey interbeds, sandstones and rare conglomerates; 4 – Ruslar Formation (Upper Eocene-Oligocene): clays, clayey siltstones and sandstones with manganese indications; 5 – Avren Formation (Eocene): marls with thin sandstone interbeds; 6 – Aladan Formation (Lower Eocene, Middle Cuisian): bioclastic nummulitic limestones; 7 – Dikilitash Formation (Lower Eocene, Lower-Middle Cuisian): quartz sands and sandstones with algal bioherms and nummulitic limestone beds; 8 – Beloslav Formation (Lower Eocene, Upper Ilerdian) – clayey sands with thin interbeds of calcareous sandstones, sandy clays and marls; 9 – Komarevo Formation (Middle-Upper Paleocene): sandy-silty limestones with lithothamnium algae; 10 – Mogila, Dobrindol, Venchan, Shumen and Mezdra Formations (Turonian - Maastrichtian): sandstones, glauconitic sandstones and limestones, bioclastic limestones, chalk; 11 – Gorna Orjahovitsa Formation (Hauterivian - Barremian): marls with rare sandstone beds; 12 – lithological boundary; 13 - faults: a – established, b – supposed; 14 – geotops.

Aladan Formation (“Aladan calcareous horizon”, [Гочев, 1933](#)) is composed of robust light bioclastic nummulitic limestones. The lower boundary is transition between the sandy limestone of the Dikilitash Formation to gray-bluish marls. The upper one is a fast lithological transition to the marls of the Avren Formation. The thickness of the unit varies between 10-15 m in the stratotype, 16-25 m in Dobrudzha and 3-4 m in Provadia Plateau. It crops out widely south and north of Beloslav Lake ([Fig. 4](#)). Fossil

content is abundant – mainly large foraminifera, bivalves, brachiopods and echinoids. [Аладжова-Хрисчева \(1984\)](#) referred these limestones to the Middle Cuisian Substage of the Lower Eocene.



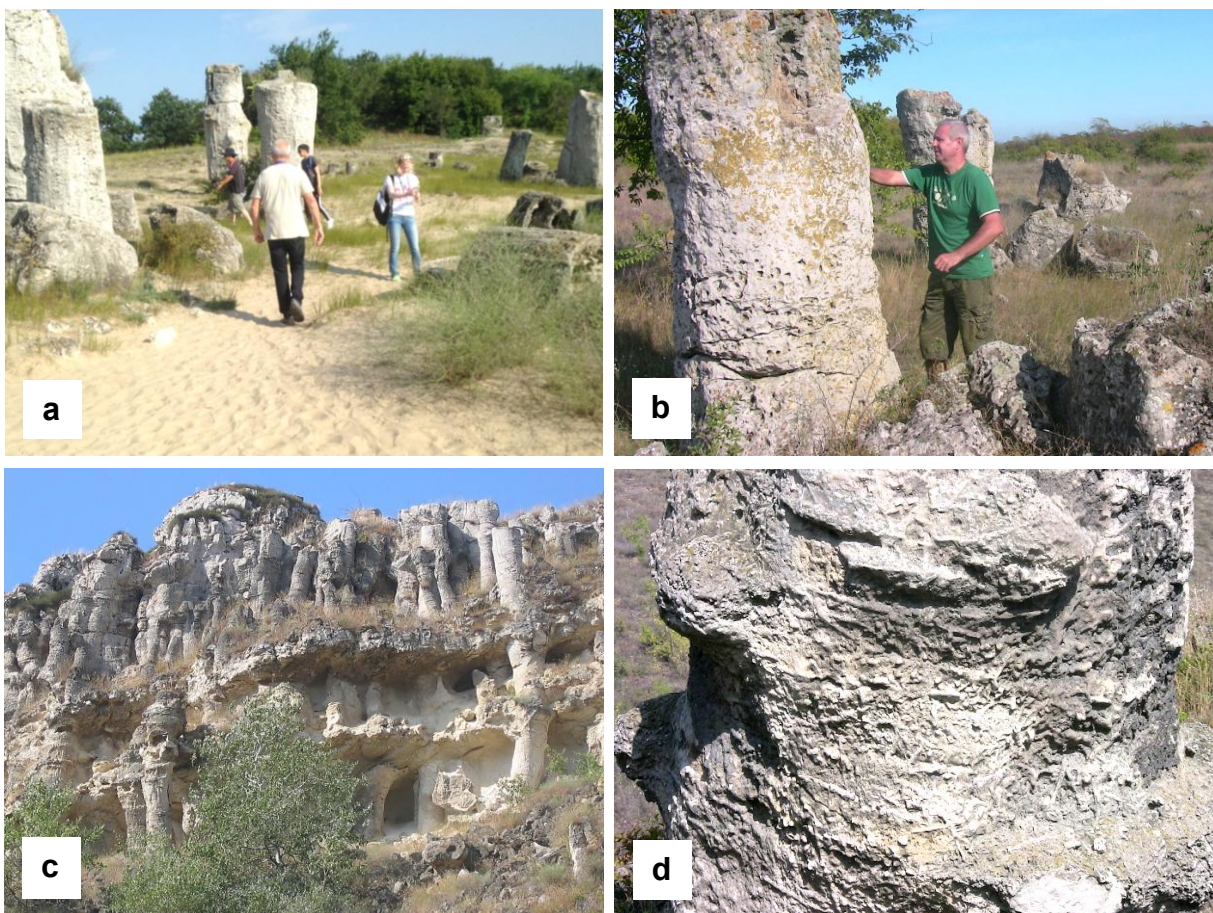
**Figure 5.** Stratigraphic column representing the evolution of the knowledge about the age of the columns containing Dikilitash Formation and the underlying and overlying sediments, based on large foraminifera

Avren Formation (“Avren marl”, [Гочев, 1933](#)) is composed of light-gray and gray-yellow marls with interbeds of sandy and silty marls, siltstones, sandstones, gravelite and conglomerate lenses. The lower boundary is fast transition from the limestones of the Aladan Formation or the sandstones of the Dikilitash Formation. The upper boundary is lithological transition to the manganiferous sandstones and clays of the Ruslar Formation. It crops out south-west and north-east of Beloslav ([Fig. 4](#)). The fossil content is mainly of small foraminifera and nannoplankton determining a wide stratigraphic range from Lower to Upper Eocene.

Generally, in the geosite areas with columns crop out three of the lithostratigraphic units mentioned above: the Dikilitash Formation containing the columns, the underlying Beloslav Formation and the overlying Aladan Formation. On the basis of large foraminifera, they have been referred to the Lutetian and Ypresian stages of the Lower Eocene by different authors ([Fig. 5](#)). [Аладжова-Хрисчева \(1984\)](#) subdivided the stratigraphical interval comprising the Beloslav and Dikilitash Formations respectively into Ilerdian and Cuisian local substages of the Ypresian global stage. According to this subdivision the Varna columns fall in the Cuisian local stage comprising the time between 54 and 47,8 Ma.

### Concept of the Varna columns

The Varna Columns are an impressive, large-scale natural wonder, a unique geological phenomenon that arouses curiosity and admiration. They are found in natural outcrops and sand quarries. Natural outcrops are located in forest glades or fields with a stony-sandy landscape, where there are single columns and rarely groups of columns (Fig. 6a). Due to natural weathering columns are with reduced height. They have eroded surfaces with many secondary features: ribs, grooves, cracks and gaps inside revealed in almost all 16 natural geotops, e.g. Center North, Centre South and others (Fig. 6b). With few exceptions, columns have no basis, cover and other primary diagnostic features. Quarries developed between 1960 and 1980 provide a sandy-stony landscape. They reveal five levels of columns with primary diagnostic features: solid bottom, full height, preserved external contacts, extensions (“kapitels”) at the base and at the top, nodules, stromatolite structures, trace fossils and oncoids (Figs. 6c,d). In “West” quarry after the sand extraction remained more than 20 protruding reefs at full height up to 5 m and 2 to 6 m in diameter, with visible hard grounds, stromatolites, trace fossils, and covers of nummulitic limestone beds.



**Figure 6.** Main characteristics of the geotops: **a**, Rocky-sandy landscape with single columns in the “Center-South” area; **b**, External surface with secondary structures: ribs, channels, cracks and gaps in the “Center-North” area; **c**, Different levels of columns (third, fourth and fifth) separated by limestone layers in the “Beloslav” Quarry; **d**, Trace fossils, oncoids, “tumuli” and other primary structures on the outer wall of a column in the “Beloslav” Quarry.

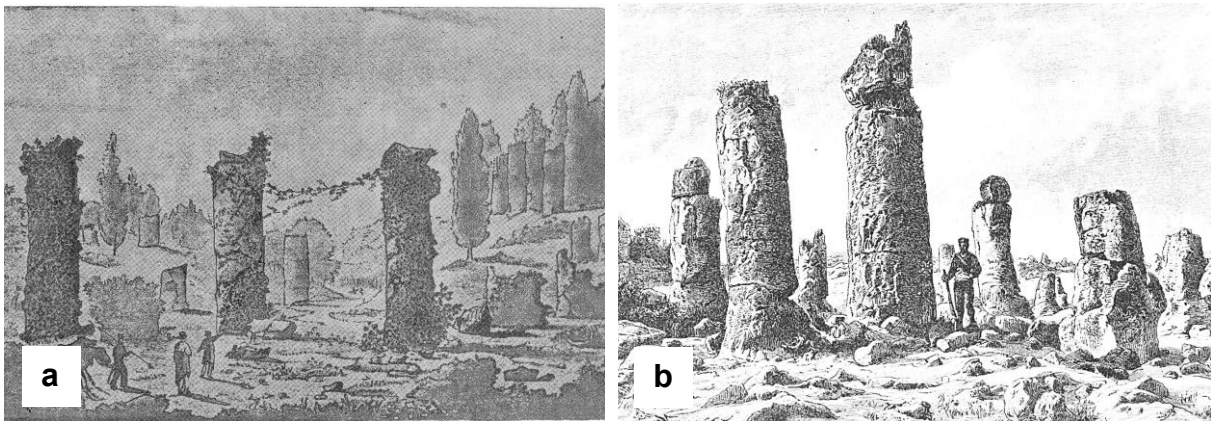
A kilometer long artificial outcrop of white sands and silts containing four levels of predominantly single reefs (columns) with a total height of 25 m is preserved in Beloslav quarry. They have a height of 3-10 m and a diameter of 0.2-8 m, with extensions (‘tumuli’), stromatolites, trace fossils and cover beds - limestones with a thickness of 0,1-1 m to 5 m for the cover of the 4th level. The large number of natural and artificial outcrops provide reliable data on the composition, morphology, primary

characteristics and nature of the columns with evidence for their reef-type biogenic origin (Начев et al., 1996).

### Origin of Varna reefs

The “Pobiti Kamani” (Varna Reefs) are among the most emblematic geological phenomena in Bulgaria. They are located at 5 levels, covering 30 m of the section of the Dikilitach Formation. This remarkable geological phenomenon has been the subject of research since the beginning of the 19th century. The shape and connections of the columns with the accommodating sands give rise to various hypotheses about their origin, which can be united into two groups: biotic and abiotic. Some of them, such as the remains of ancient temples, weathering formations or petrified forests, now have only historical value. Others have been renewed in the light of the latest theoretical developments in sedimentology or transformed into new hypotheses, which will be briefly discussed. The hypotheses about the origin of the columns are consistent with the time of their occurrence.

Abiogenic hypotheses explain the formation of the columns with the effect of physical factors without the participation of marine organisms. The first evidence about the Varna columns belongs to the Russian correspondent from the Russian-Turkish War in 1829 [Тепляков \(1833\)](#). He called them „remains of columns of temples or palaces” of ancient „mythical cyclope tribe” ([Fig. 7a](#)) but also allows their natural origin.

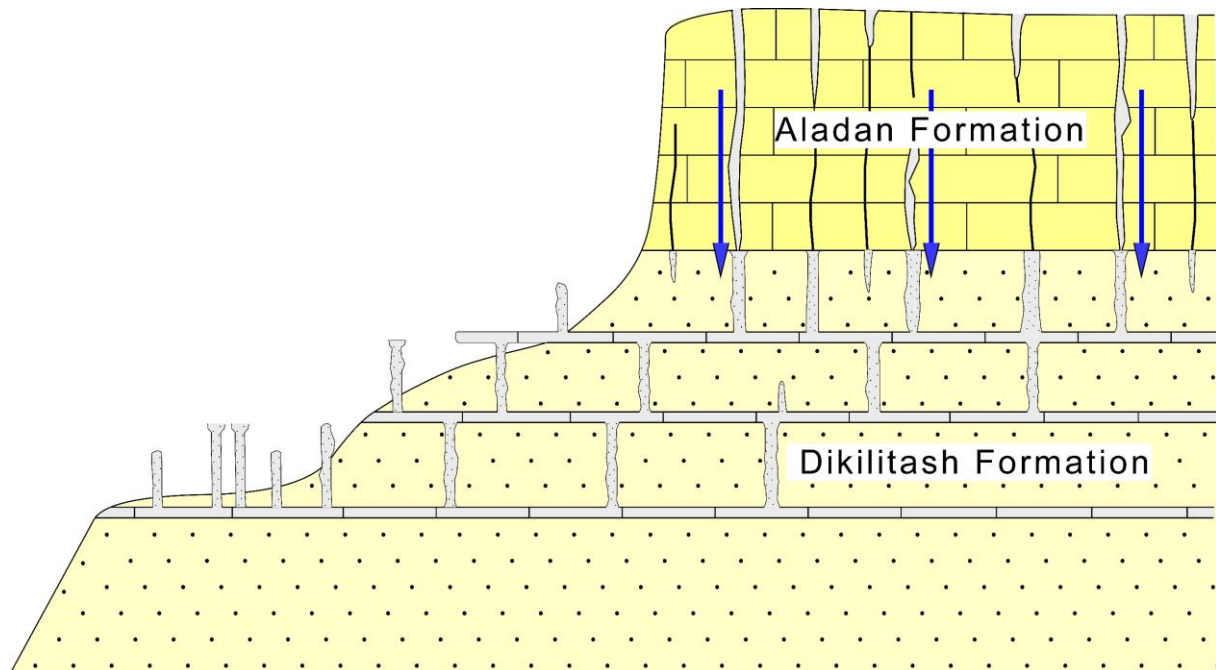


**Figure 7.** First graphic illustrations of the Upright stones: **a**, Graphics of the columns by [Тепляков \(1833\)](#); **b**, [Toulas's \(1890\)](#) illustration of the columns.

Weathering hypotheses consider the columns as residual forms of contemporary processes of weathering that have occurred under the action of air and water ([Spratt, 1856, 1857](#)), surf ([Бакалов 1921, 1922; Lahn, 1939](#)), wind deflation ([Gellert, 1929, 1932](#)), contemporary processes of weathering ([Ehrenberg, 1938](#)), other physical factors ([Ulbrich, 1939](#)). [Toula \(1890\)](#) also reviewed the “upright or erect stones” but did not consider their origin ([Fig. 7b](#)). General weakness of the weathering hypotheses is the absence of sandstone among the host sands, making them unverifiable. According to the concretion hypothesis ([Шкорпил, Шкорпил, 1921](#)) the “upright stones” are formed as “calcareous concretions” in bursting “sandstones”. This concept is also supported by [Мандев \(1955, 1970, 1971\)](#). Another variant of this hypothesis is that they are the result of cementation of calcareous sand from water by downward or lateral migration. Cylindrical, spherical and tree-like objects are also accepted as nodules by many authors.

Infiltration hypothesis ([Fig. 8](#)) has long been very popular. It was launched by [Гочев \(1933\)](#) and supported by [С. Бончев \(1934, 1938\)](#) and [Е. Бончев \(1970\)](#). This hypothesis explains the origin of the columns with the migration of rainwater penetrating the overlying limestone and mobilizing

bicarbonate, which seeps deeply in the sands and consolidates them into vertical sandy-carbonate pillars. According to [E. Бончев \(1949, 1955, 1970\)](#) the formation of pillars is similar to the formation of stalactites in caves. However, stalactites have no internal cavities, clastic minerals, glauconite, pyrite and nummulites as seen in the columns. Moreover, practical experiments has shown that, when penetrating sand, the water spreads downward and sideward due to capillary motion, forming three-dimensional bodies rather than columns. The presence of different levels of reefs with thickness 25 m also refutes this hypothesis.

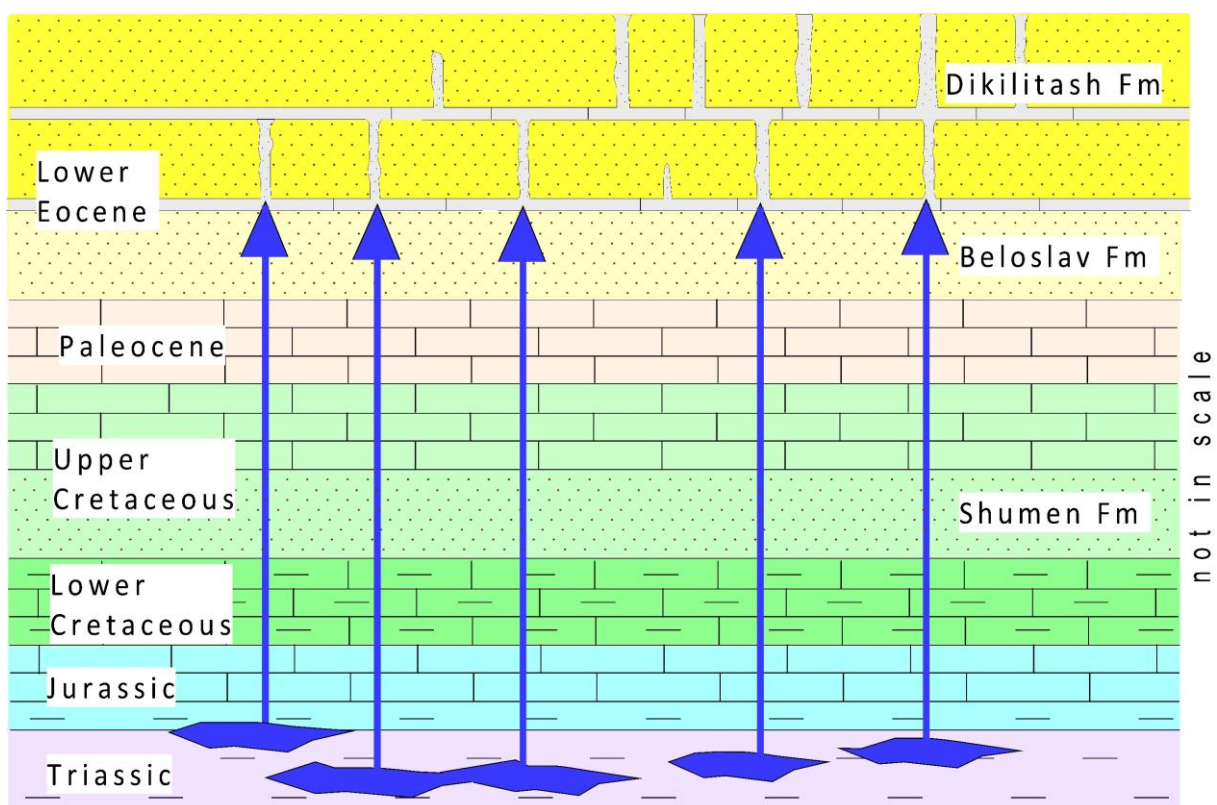


**Figure 7.** Illustration of the infiltration hypothesis supported by [Гочев \(1933\)](#), [С. Бончев \(1934\)](#) and [E. Бончев \(1970\)](#): the arrows indicate the water inflow from above enriched in carbonate

Of the biotic hypotheses, the earliest is the biogenic reef hypothesis, which explains the formation of stone pillars by the activity of coral polyps attached to the bottom ([Радев, 1939](#)). Colonial corals, however, do not grow on sandy bottoms. This is confirmed in the region by occasional finds of single corals in the columns.

Hypothesis about the stone forest is associated with the formation of petrified forests ([Margos, 1960](#)) by fossilization of trees or replacement of stems by terrigenous-carbonate material after their rotting under sea water. After diagenesis this material was consolidated and stored as a stone forest. Proof of this are the traces of boring mussels (*Teredo*) in columns ([Skacel, 1963](#); [Panos, Skacel, 1966](#); [Давиташвили, Захаријева-Ковачева, 1963а,б](#); [Захаријева-Ковачева, 1969](#)). Columns are defined as upright, cylindrical pillars, built of sedimentary material with central gaps that result from the rotting of the stems. They are not petrified tree trunks, but only their crusts preserved as a "covering structures" around the trunks, consisting of quartz sand and other mineral admixtures and calcite cement ([Давиташвили, Захаријева-Ковачева, 1975](#)). In fact, on the outside the columns are composed of sandy limestone and sandstone with calcite cement. The central cavities of the stems are weathering formations, and the "roots of mangrove plants" are actually trace fossils. The idea of successive and large-scale existence of five forests on top of each other in the Ypresian sea (corresponding to the five levels of columns) is quite unrealistic.

Recently the methane-derivative hypothesis has been promoted to explain the famous geological phenomena near Varna. According to this hypothesis, first suggested by Botz et al. (1993) and Walter (1993, 1994), a key role in calcite precipitation and formation of the columns has the oxidation of hydrocarbon-bearing fluids in their upward migration (Fig. 9). According to this theory the subvertical cylindrical columns are chimney formation along the vertical path of an ascending gas-bearing fluid through the permeable unconsolidated sandy host sediments. The relationships between methane migration and formation of carbonate-cemented sandstone columns is explained by the strongly reduced amount of  $\delta^{13}\text{C}$  in carbonate cement of the columns (De Boever et al., 2006; 2008a,b; 2009). According to these authors Varna columns are “methane seepage-related tubular sandstone concretions”, formed by low-magnesium calcite cementation of the unconsolidated host sediments around the ascending methane-bearing fluid plume, triggered by the microbial mediated anaerobic oxidation of methane. They claim that vertical migration of fluids has been going on tectonically controlled pathways, as evidenced by the linear arrangement of the columns along the faults, and therefore the Paleogene fault system has played a major role in directing fluid movement. As sources of hydrocarbons are considered Triassic and Jurassic rocks penetrated in boreholes of the eastern part of the Moesian Platform. However, the results of these boreholes, including recently bored R-1 Golitsa (2008) show that Triassic and Jurassic rocks in this part of the country are completely devoid of hydrocarbons.



**Figure 8.** Illustration of the methane-derivative hypothesis supported by Botz et al. (1993), Walter (1993, 1994) and De Boever et al. (2006; 2008a,b; 2009): vertical migration of fluids from Jurassic and Triassic along tectonically controlled pathways, feeding the location of the columns

Tubular concretions - products of ancient methane seepage have been described in different parts of the world, but the factual analysis raises serious doubts that this is the case with the “Upright stones”. Reviewing the hypotheses of their origin, Nachev, Sinnyovsky (2014) put forward several

scientific and purely logical arguments that contradict this theory. The general weaknesses of this hypothesis can be summarized as follows:

1. Cryptocrystalline calcite (sparite) in the cement of the columns is of biogenic (not microbial anaerobic) origin as evidenced by the presence of algal filaments, bacterial peloids, stromatolites, oncoids, serpula buildings and trace fossils in thin sections;
2. Most of the faults are post-Eocene formations (see Figs. 2,4) and therefore they are younger than column's formation, so the fault system could not have played any role in hydrocarbon migration during the Eocene because it did not exist at that time;
3. Linear arrangement of the columns (along the faults) is simply not observed;
4. The columns of the higher level do not always inherit the columns of the underlying level (see Fig. 6c);
5. Methane migration from Eocene deposits is in contradiction to the abundance of benthic fauna among the host sands and inside the columns;
6. The outer wall of some columns is intensively bioturbated (Fig. 6d) which is impossible if the columns were formed by gases entering through already deposited layers, because the burrowing organisms live in the upper 10 cm of the sediments.
7. Columns are missing among the sands of the Beloslav (Lower Eocene) and Shumen (Upper Cretaceous) Formations which have similar lithology (loose sandstones) and were also on the path of the upward hydrocarbon migration (Fig. 9);
8. Triassic and Jurassic sediments in this part of the country are completely devoid of hydrocarbons. Recent proof is the borehole R-1 Golitsa drilled in 2007 which was estimated as the "driest" well in the area.

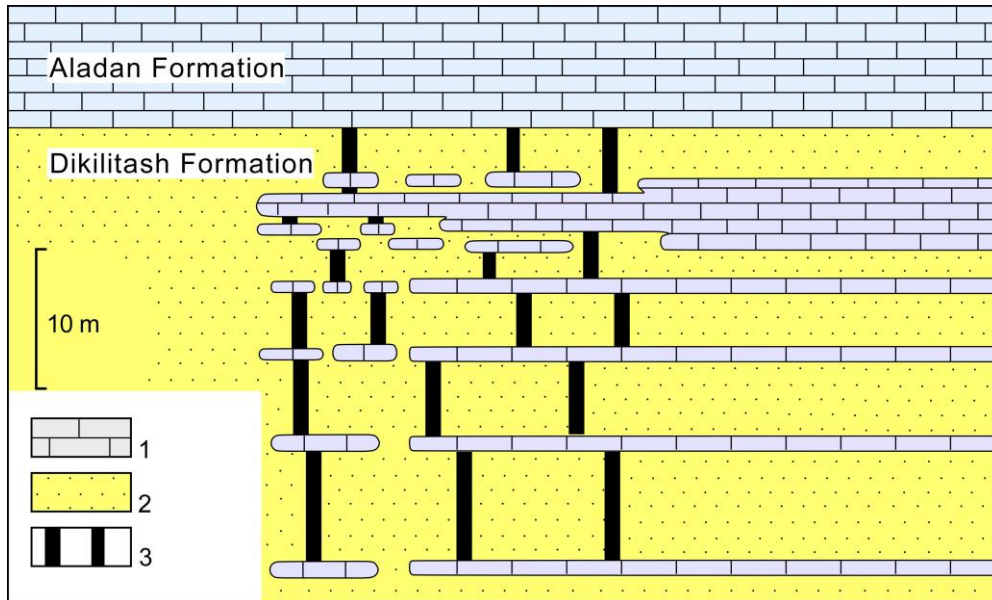
The hypothesis of algal bioherms is based on the ability of algae to generate micrite and build bioherms on limestone bottoms with carbonate outer zone and inner primary area of white sand with stromatolites, oncolites, ichnofossils, mussels and many benthic fossils - nummulites, discocyclina and small benthic foraminifera (Начев et al. 1986a,b). Algal-annelid hypothesis postulates that "annelid reefs" are cemented sandstones from annelid worms in symbiosis with calcareous algae (Pamoukchiev, 1996). This assumption overestimates the role of the annelid worms to produce such biogenic structures.

Supporting the microbial origin of the columns Nachev, Sinnyovsky (2014) examined some new evidence from surface outcrops, including quarries, and laboratory analyses in support of this theory. According to the adopted by the authors concept Varna reefs are marine biogenic structures formed in shallow Ypresian sea 48-53 million years ago. In its littoral zone were deposited white, well sorted sands and silts. Closer to the shoreline, which was located north of the villages Banevo and Slanchevo, were deposited sands while to the south dominated silt deposits. In the areas where columns were set, sea currents and waves revealed carbonate solid bottom and provided local conditions for reef development. The rest of the Eocene Sea had a sandy bottom without the necessary conditions for reef-building (Начев, Начев, 2001a,b). Generalized facial scheme of the five levels of columns is illustrated on Fig. 10.

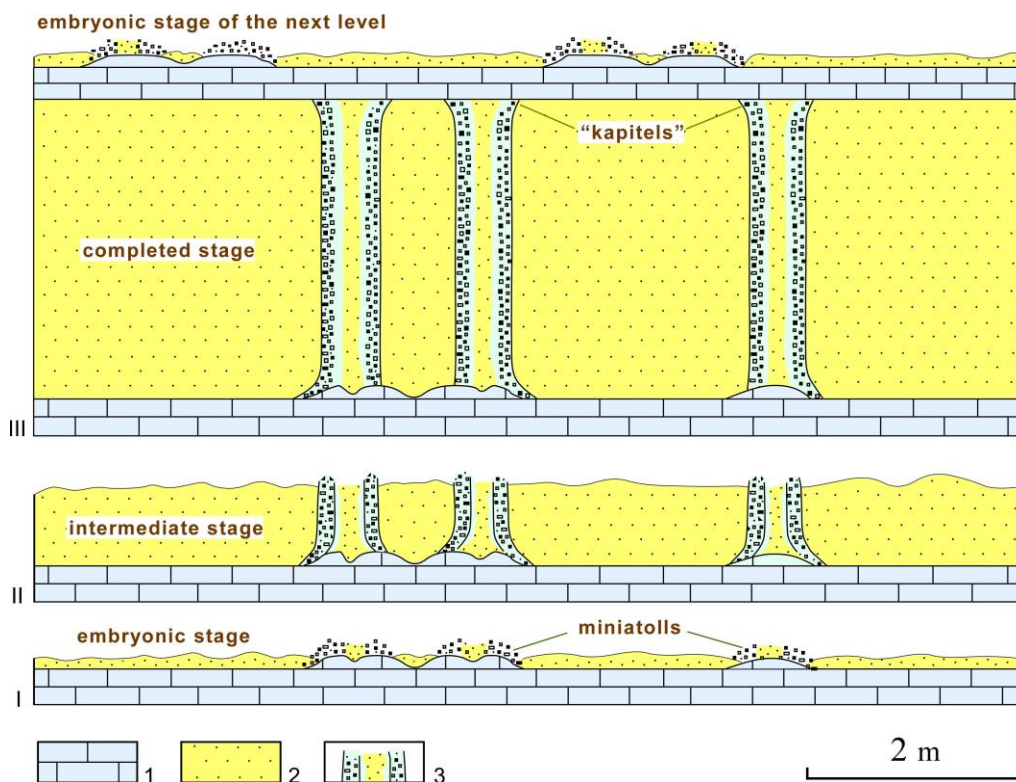
Reefs have evolved following recently known mechanisms for reef formation in nature, such as columnar structures that grow vertically as sand accumulates around them to remain afloat. According to Начев, Начев (2001a,b) emergence and growth of the reefs in every level passed through three successive phases (Fig. 11).

(1) During the initial (embryonic) stage on the limestone pads shallow marine benthic cyanobacteria biocenoses developed – blue-green calcareous algae and bacteria (Fig. 11-I). As a result of

photosynthesis and metabolism they began separating microbial carbonate (micrite), aragonite and calcite. Calcite (70%), mainly in the form of micrite, was a key mineral for the formation and growth of reefs. They attached mass shallow marine benthic organisms: calcareous algae, large foraminifera (nummulites, discocyclina), small foraminifera, mussels, mud-feeding worms (annelids) and others.



**Figure 10.** Generalized facies scheme of the five column levels in the Dikilitash Formation (after *Начев & Начев, 2001b*).



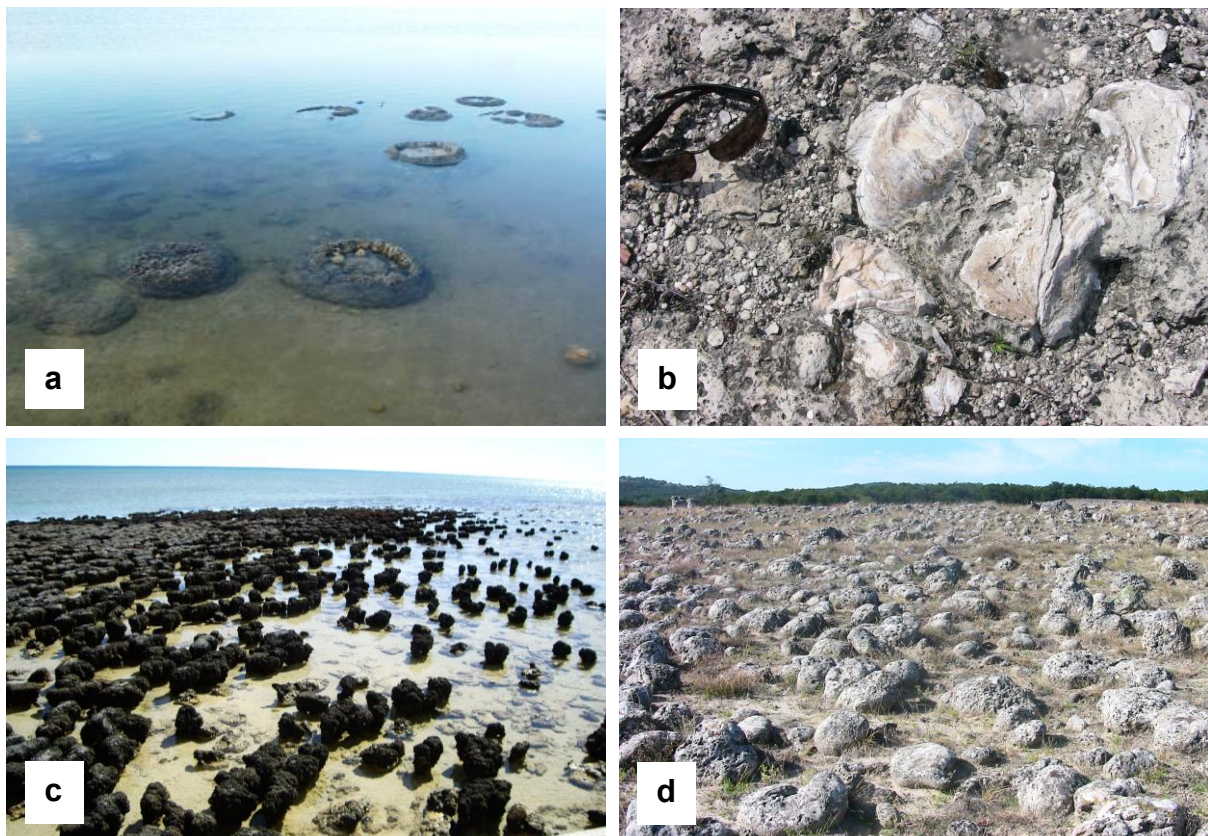
**Figure 11.** Origin and growth of the reefs (after *Начев & Начев, 2001b*): I – initial stage; II – intermediate stage; III – completed stage; 1 – limestone, 2 – sand, 3 – reefs

(2) During the intermediate stage started the initial growth of the miniatolls (Fig. 11-II). Their increase was synchronous, as it depended on subsidence of the bottom and rate of sand accumulation

which compensated the subsidence. The upper part of the reefs was close to sea level as can be seen in the modern environment (Fig. 12a), while the level of the sand was lower. The growth of the columns was a response of reef-building organisms to compensate for the sand sedimentation. Some miniatolls have been able to compensate for the sand accumulating around them and have formed columns. When the rate of sand sedimentation exceeded the growth of the miniatoll, the development of embryonic reefs has ended prematurely.

(3) Finally, due to both moderation of subsidence and reducing the rate of sand influx the columns were covered with limestone layer due to the complete colonization of the bottom by the reef-building organisms (Fig. 11-III). The so called “kapitels” in the upper part of the columns were formed as a result of the extension of the miniatolls preceding the colonization of the bottom.

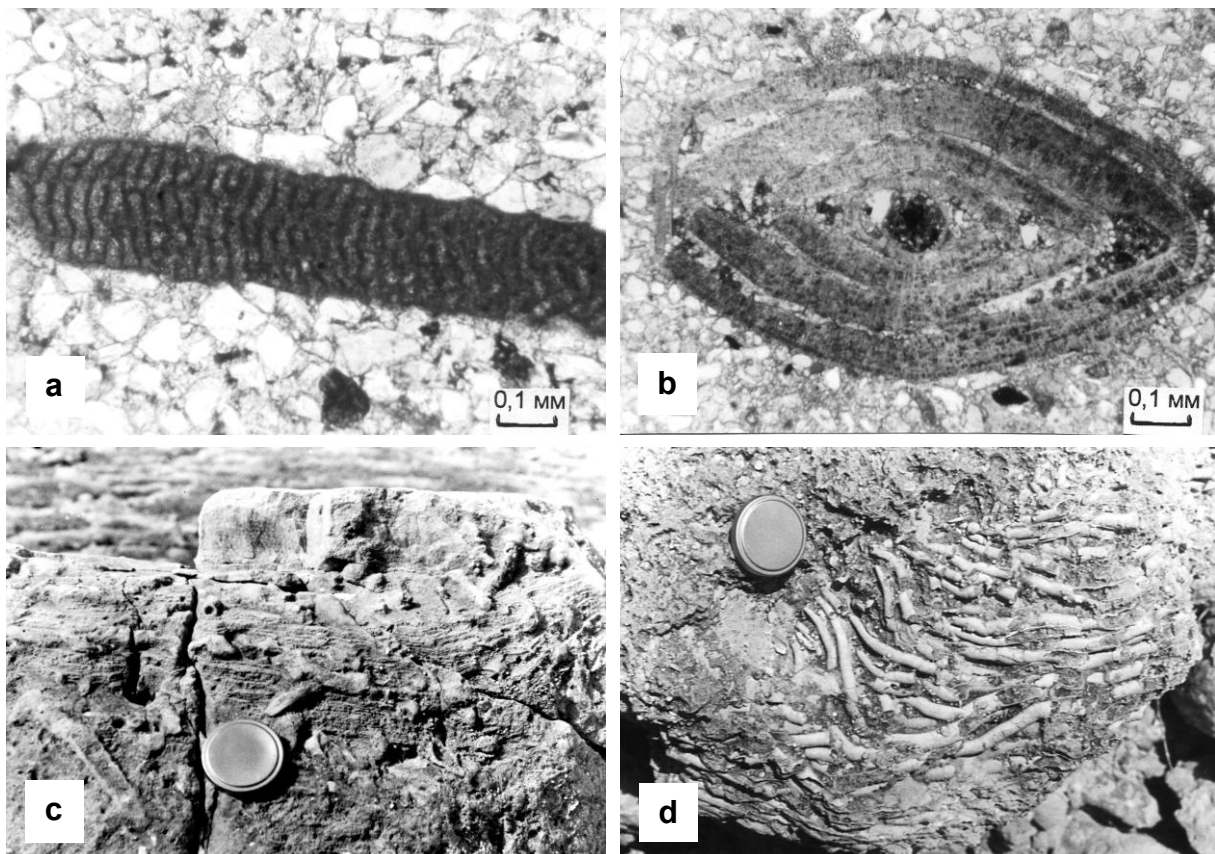
This is an excellent example of the process called ‘taphonomic feedback’ described by Kidwell & Jablonski (1983) and Kauffman et al. (1991). In this case it began with the spotting of miniatolls scattered on the sandy bottom of the Early Cuisian Sea (the base of the first level of columns on Fig. 4) well illustrated by modern stromatolite miniatoll formation in Thetis Lake, Australia (Fig. 12a, Parks and Wildlife Service, 2017). Sustainable subsidence of the bottom compensated by sandy sedimentation may cause the miniatolls to grow as columns. Due to favorable conditions for benthic organisms an expansion of reefs and colonization of the entire bottom occurred which resulted in formation of a biogenic limestone layer composed of large foraminifera and larger representatives of benthic fauna, such as oysters of *Ostrea rarelamella* (Fig. 12b), cephalopods (*Nautilus*), colonial corals etc.



**Figure 12.** Modern and fossil elements of the “taphonomic feedback” process: **a**, Spotting of stromatolite miniatolls (thrombolites) on sandy bottom in Thetis Lake, Australia (Parks and Wildlife Service, 2017); **b**, Oysters of *Ostrea rarelamella* in a limestone bed at the base level in Beloslav quarry; **c,d**, Comparison between modern mould field in Shark Bay, Australia (Flickr, 2007) (c), and fossil mould field on the bottom of the Eocene Sea in „Slanchevo West“ area (d).

In modern environment such a reef-building process is in operation in the Shark Bay, Australia, where stromatolith formations called “moulds” are strikingly similar to the Eocene “moulds” in Slanchevo West area (Figs. 12c,d). Moulds in Shark Bay refer to the various types of microbial mats, which are fossilized or living structures formed by microbial communities, primarily cyanobacteria. Fossilized stromatolith buildings with large, agglutinated domes and columns are described in the Neogene by Riding (2000). In our case, the limestone layers separate columns of five levels, indicating a five-fold repetition of this process. After restoration of sandy bottom reef-building confined again in separate islands. Some reefs continue their development to the next level. In other places, directly on the newly formed limestone layer, new miniatolls develop as columns.

Obviously, the main controlling factors of the reefs’ growth are the subsidence of the sea floor and the rate of sedimentation of the host sands. When the rate of sedimentation is higher than the subsidence the sandy bottom was formed, respectively when the sandy sedimentation decreased the taphonomic feedback caused the formation of a limestone layer. Genetic model for the origin of the Varna microbial carbonate reefs is similar to that of recent oceanic atolls, but at a scale of miniatolls, proved by the morphology of the reefs and their structure with outer limestone zone and inner zone of loose sands. They differ from typical atolls in the following aspects: (1) small size, (2) quartz impurities in the limestone and (3) lack of lagoon sediments (dolomite and evaporites) inside them. Therefore it is assumed that their formation was performed on the model of miniatolls (Начев, Начев, 2001a,b).

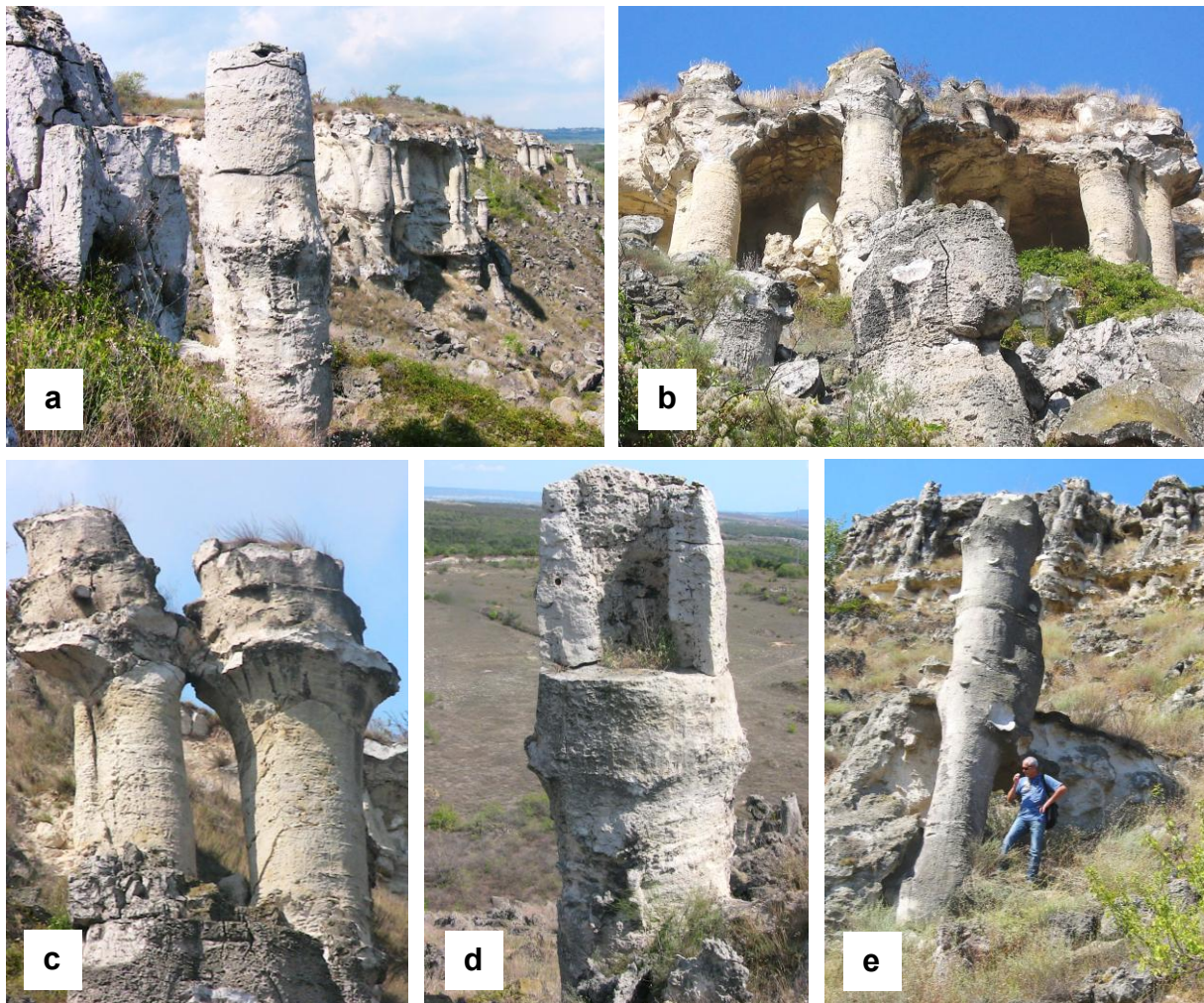


**Figure 13.** Microscopic and macroscopic structures of the reefs (after Начев, Начев, 2001b): **a**, Filament of calcareous algae in cryptocrystalline micrite; **b**, Cross section of nummulite shell; **c**, Seasonal stromatolite lamination and cross trace fossils in “Center-South” area; **d**, Annelid tube worms *Serpula* in the same area.

Despite diagenetic changes the fossil Varna reefs have kept most of the elements of modern miniatolls. Weathering and erosion, however, changed or deleted many of them, which led to the creation of various theories of their genesis. Weathering processes have begun to destroy the columns from top to bottom, immediately after the destruction of the younger rocks. Atmospheric agents caused dissolution of carbonate and partial demolition of their periphery. This led to the formation of secondary weathering grooves and ribs. After cracking and opening the bottom of the columns, rainwater began to wash away the sand of the central part. Thus, the central cavities were formed, accepted in the past as cores of tree trunks. Considering loose character of the sand, the weathering processes act very quickly. In the western vertical front of Beloslav quarry rainwater and wind in a few years destroyed the white sands and silts between columns and formed niches.

### Mineral composition and morphological characteristics

The mineral composition of the reefs is mainly of calcite and autogenous extraclastic quartz (Начев, Начев, 2001b). Under the microscope calcite is observed as a dark cryptocrystalline micrite and light calcite cement. In the micritic substrate filaments of calcareous algae and calcified bacterial aggregates are visible (Fig. 13a). These features are evidence of microbial carbonate, formed by photosynthesis and metabolism of cyanobacteria - blue-green calcareous algae and bacteria. This proves marine microbial-carbonate origin of bacterial-algal biogenic bodies. The presence of nummulites (Fig. 13b) is also characteristic feature of the reefs, because they have a rock-forming role.



**Figure 14.** Morphological features of Varna reefs in “Beloslav” quarry: **a**, Cylindrical columns and complex biogenic structures; **b**, Cylindrical columns in fourth level covered by thick limestone layer; **c**, ‘Kapitels’ in the upper part of the columns at their junction with the covering limestone layer; **d**, Central cavity in a single column; **e**, Single irregular column.

Stromatolites, oncoids and serpula bodies are biogenically formed in situ. Stromatolites consist of flat, dark and light seasonal laminae, determined by microbial carbonate precipitated by calcareous blue-green cyanobacteria (Fig. 13c). Serpula bodies are determined by the vital activity of tubicolous annelid worms and intense burrowing bioturbation (Fig. 13d). Following the existing data, the Varna reefs are marine structures formed on the bottom of the shallow Eocene Sea during the Cuisian age between 53 and 48 million years ago. On the bottom many moulds arose (Fig. 12a), but most of them were covered with sand and only a few grew as columns. These are real geological bodies in the form of cylindrical or irregular columns, or complex biogenic structures of consolidated rocks placed among loose sands and silts (Figs. 14a,b). Reefs are located between nummulitic limestone beds at 5 levels with a total height of 30 m. The fourth level is covered by a 5 m thick nummulitic limestone layer. Another thick nummulitic limestone covers the fifth level.

The size of the reefs is 0,2 m (embryonic) to 10 m. The first level has a height of 10 m, the second one - 7 m, the third one - 5 m, the fourth one - 3-6 m and the fifth one - 5 m. The diameter of the single reefs is up to 2 m, and of the complex reefs – up to 6 m. Internal columns in groups of reefs have a polygonal section. Contact with the host sands is clear and sharp with the presence of glauconite and pyrite.

Varna reefs have a zonal structure with a solid outer zone of sandy limestone, with gradual transition inward to calcareous sandstone or siltstone. In the single columns additional peripheral oncolite zone is formed. Reefs grow only on hard limestone substrate (solid bottom) as their base is wider. Rarely embryonic reefs up to 50 cm in size are encountered, with conical ends upward in the sand. At the top reefs pass with extensions – ‘kapitels’ into the covering limestone layer which is the base of the next level (Fig. 14c). They have also rings and extensions – ‘tumuli’ associated with internal limestone layers or lenses, which often determine the double cone shape or forms resembling a throne, mushroom, or umbrella. Lithological composition of the columns is variable. External solid zone consists of sandy (silty) limestone, passing inward to calcareous sandstone or siltstone. The inner zone consists of white quartz sand and silt. In outcrops the weathering causes destruction of the sandy limestone from the inside, and form secondary longitudinal grooves and transverse cracks. In the open reefs rainwater washes the sand from the inner zone and forms internal (central) cavity (Fig. 14d). Rare are encountered well preserved singular irregular columns (Fig. 14e).

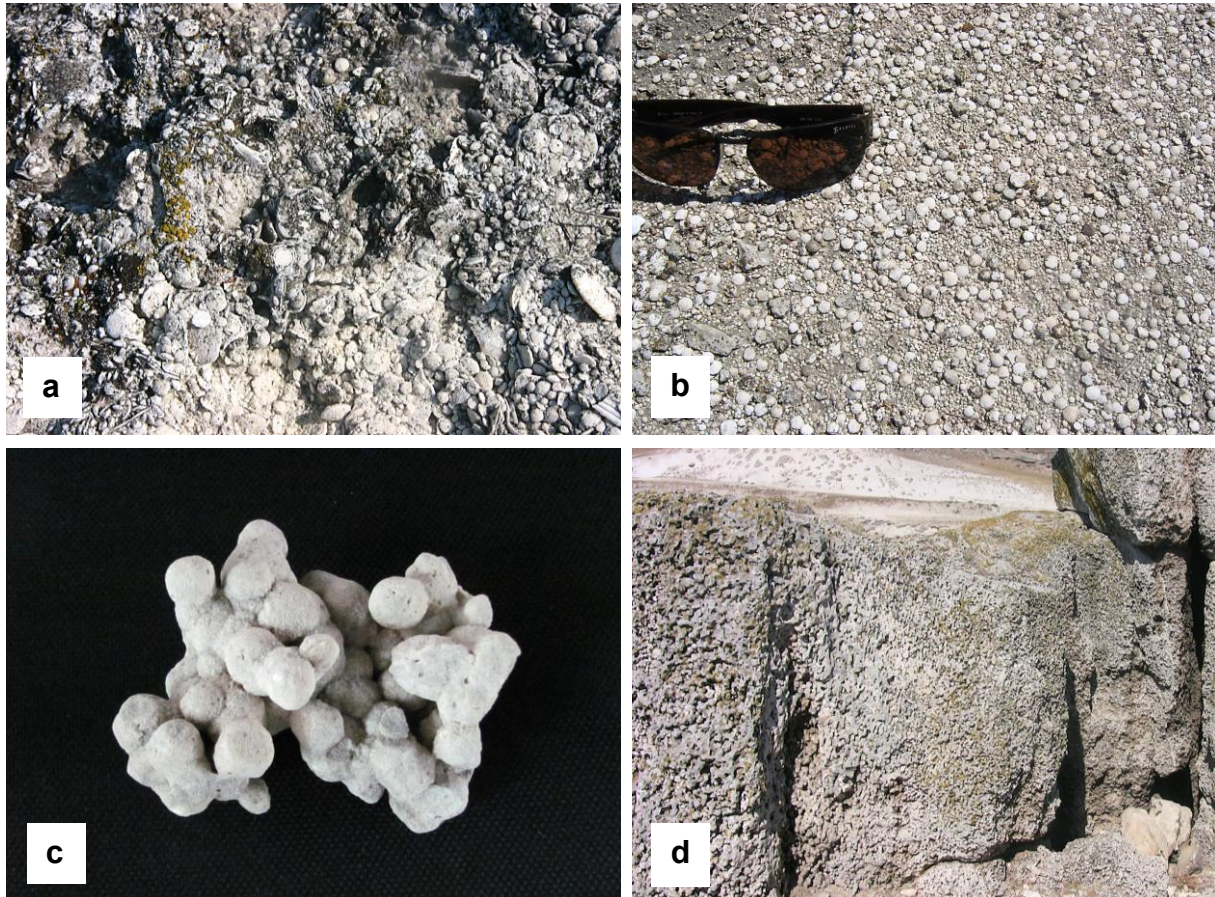
Many of the reefs are composed entirely by nummulite shells (Fig. 15a) which are dispersed also in the host sands (Fig. 15b). Oncolites (oncoids) are rarely encountered in the form of spherical, irregular bodies in cluster size up to 20 cm, with core and concentric layers of carbonate-microbial origin (Fig. 15c). They form also peripheral oncolite zone in the outer wall of some reef structures (Fig. 15d).

### **Geoconservation significance**

Varna reefs are unique geological formations that do not have full analogue in the world. So far in geological literature, similar or analogous formations have not been reported. Their morphology and genesis caused great scientific interest in a third consecutive century. This determines their extremely high scientific and educational geoconservation value.

Genetically Varna reefs belong to the class of geomorphological erosional forms, but they should not be referred to any of the modern environments (processes and landforms) reviewed for example by Gray (2004). The protected area is an island of subarid landscape within an area of moderate

continental climate. The larger outcrops of the Dikilitash Formation are characterized by a desert landscape (Fig. 16a). Proximity of the geosites to the sea makes the climate milder than inland but here typical arid plants and animals encounter such as cactuses (Fig. 16b) and small scorpions. These environmental contradictions make the area more attractive for modern geotourism in the means of Hose (2012).



**Figure 15.** Biogenic and abiogenic structures of the reefs: **a**, Reef composed of nummulite shells in “Beloslav West” area; **b**, Abundant nummulites in the sands of “Beloslav” quarry; **c**, Oncoides from “Center-South” area, donated by prof. R. Kostov to the Museum of Geology and Paleontology in the University of Mining and Geology “St. Ivan Rilski”; **d**, Oncolite zone on the side wall of a reef structure in “Slanchevo South” area.

The proximity of the geological phenomenon to Varna city and the resort “Golden Sands” predetermines a great tourist interest. It can be developed as a Geopark area with guaranteed high attendance due to the well-developed coastal tourism. As mentioned by Newsome & Dowling (2006) accounts of landscape evolution are written for virtually every part of the world, and an impressive diversity of rocks and minerals have been comprehensively described. In this case, however, it comes to well-exposed unique formations from Eocene epoch which deserve to be seen by visitors all over the world. This could be achieved only within a professionally designed Geopark. Geotourism should be focused on perfectly preserved original marine conditions and pillar reef formation. Developing of purposebuilt access roads, visitor centers, interpretive sites, bus tours, bike lanes and hiking trails will contribute to the future geopark infrastructure.

The Center South area of the “Upright stones” is visited by many people: geologists, geographers, archaeologists, botanists, as well as tourists, naturalists, travelers, students and conference participants (Fig. 15c,d). However, the visitor centre in the “Centre South” and “Center North” areas with brief and nonprofessional information about the columns is extremely insufficient. Varna reefs

have very high scientific potential and deserve sustainable protection and promotion. The protected areas should be integrated into a national geopark to be proposed to the European Geoparks Network. The great paleontological value of the geosites considering their rich nummulitic content, should be used for preparing fossil collections for the purpose of geo-education. Opening of new visitor centers, 'discovery centers', interpretative centers, etc., will be a successful supplement to the sustainable coastal and marine tourism traditionally developed in Varna region. For this purpose, the creation of a visitor center in Varna looks appropriate, with geological museum and equipment for presentation of the geological history of the region, the way of origin of reefs, biodiversity and information for the semi-arid landscape, unusual for this latitude.



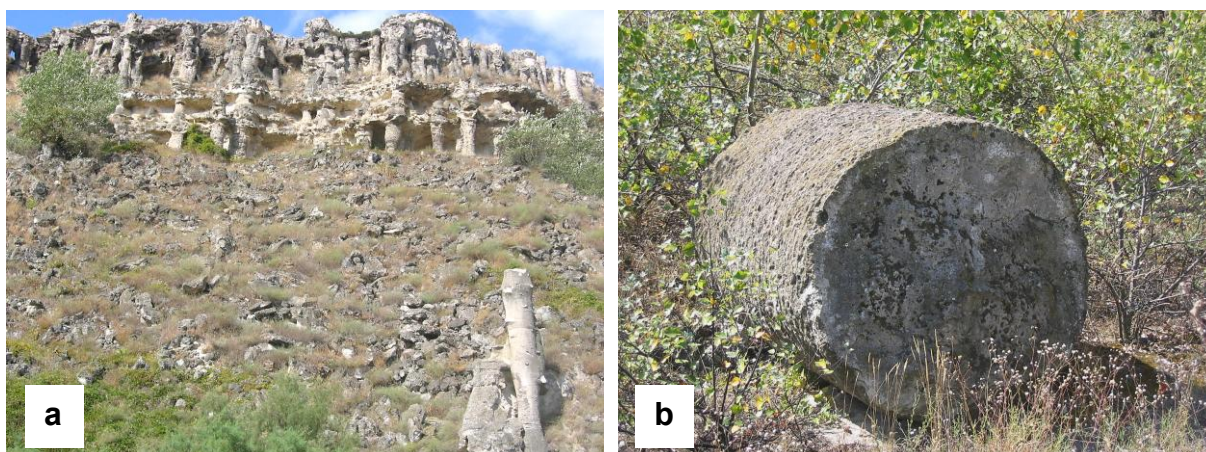
**Figure 16.** Exotic landscapes in the geosite areas attract many tourists and scientists: **a**, Desert landscape in Slanchevo West area; **b**, Flowering cactuses in Beloslav West area; **c**, Field workshop in Center South area during an international conference; **d**, Tourists in Center South area.

**Table 1** Protected areas of upright stones in Varna Region

Name	Settlement	Municipality	State Forestry	Area
Banovo	Banovo	Suvorovo	Suvorovo	29,1 ha
Beloslav Quarry	Beloslav	Beloslav	Suvorovo	30,5 ha
Slanchevo West	Slanchevo	Aksakovo	Varna	79,8 ha
Slanchevo South	Slanchevo	Aksakovo	Varna	33,7 ha
Centre North	Slanchevo	Aksakovo	Varna	0,9 ha
Centre South	Slanchevo	Aksakovo	Varna	16,3 ha
Quarry West	Slanchevo	Aksakovo	Varna	1,2 ha
The Sharp Hill	Strashimirovo	Beloslav	Varna	1,1 ha
Strashimirovo	Strashimirovo	Beloslav	Varna	2,4 ha
Teterlika	Beloslav	Beloslav	Varna	5,3 ha

Beloslav West	Beloslav	Beloslav	Varna	3,7 ha
The Naked Peak	Beloslav	Beloslav	Varna	2,7 ha
Avren Meadow	Beloslav	Beloslav	Varna	0,5 ha
The Apiary	Avren	Avren	Varna	7,7 ha

The first protection order dates from 1937, and since then the status of the area has changed many times - from natural landmark to protected area and part of the Nature Park "Golden Sands". According to the ordinance of the Ministry of Environment from 1995 the "Complex Upright Stones" is declared as "protected natural object of international significance for protection of unique geological formations". According to the next Ordinance of protection from 2002 the area is reclassified into protected area under the name "Upright stones" with total area 253,3 ha, but the rock monuments are united into 14 protected areas with total area 215 ha (Table 1).



**Figure 17.** Cleaning of the slope along the front of the „Beloslav“ quarry (a) will provide large fragments of columns (b) for open-air museums all over the country.

The difference is due to additionally included areas of the forestry estates of Suvorovo and Varna according to the last forest project. Actually, the total forestry estate including the protected areas of upright stones is 2965,2 ha of the State Forestry Suvorovo and 2070,9 ha of the State Forestry Varna. All this area, including 18 geotopes in 14 groups of geosite areas, could be united into a geopark with total area of 5036,1 ha.

### Conclusion

This protected area is not large enough to stimulate the local economic activity and sustainable development. However, it will be a successful addition and diversification of the well-developed traditional coastal tourism in Varna district and will contribute to popularising the local traditions and specific cultural and historic heritage of the area. On the other hand, this will provide a possibility to promote the unique geological phenomenon "Upright stones" among the tourists coming here from all over the world.

The development of National Geopark should be made in the light of the four types of value: intrinsic value, cultural and aesthetic value, economic value, research and educational value (Doyle & Bennett, 1998) but the economic value should be restricted to the reasonable use of sand when uncovering the reefs. A good initiative should be cleaning of the most representative geosite - Beloslav quarry for scientific and educational tourism. This will create conditions for inclusion of the site in national educational programs devoted to the Bulgarian natural heritage such as school and student excursions or, for example, a major tour for promoting the geological heritage like the Italian initiative for promotion of the geological heritage in the secondary schools (Magagna et al. 2013). On the other

hand, the cleaning of this large area will provide fragments of columns (Fig. 16a,b) for the natural museums in the country or, for example, arranging open-air museums in schools, municipalities, universities, etc., as suggested by Синьовска & Синьовски (2011). This may be a crucial step towards a wide dissemination of the principles and values of the geoconservation and development of a modern European Geopark "Pobiti kamani".

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