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New geological and X-ray diffraction data from sedimentary rocks in the area of *Underwater Petrified Forest* natural phenomenon, Sozopol Bay, Black Sea

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Нови геоложки и рентгенофазови данни за седиментни скали от природен феномен *Подводна вкаменена гора* в акваторията на Созополски залив, Черно море

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Abstract. The current study is part of a comprehensive investigation of the natural phenomenon Underwater Petrified Forest, which has no analog in the Black Sea and is very rare worldwide. The team aims to conduct a comprehensive study of the unique habitat, paleontological and geological phenomenon, the Petrified Forest, and to address a series of scientific questions. This research sheds light on the sedimentation processes related to the fossilization of tree species. X-ray phase analyses were used to compare clay rocks that encase and cover the fossilized trees.

Keywords: petrified forest, Black Sea, sedimentology, X-ray diffraction.

Introduction

The natural phenomenon *Underwater Petrified Forest* is not only unique for the Black Sea region, but very rare worldwide as well. The first studies in the Sozopol Bay were carried out four decades ago and CUBA diving confirmed the existence of numerous petrified trunks at depths between 16 and 20 m. This pioneer study provides information mainly on the type of organic matter and initial data on the pattern and conditions of formation of the *Petrified Forest*, but also poses many unanswered questions. The present work provides first X-ray diffraction data on the underwater sedimentary rock sequences described at the vicinity of the fossilised tree trunks, which are mainly represented by clay sediments, resulted by the sedimentation settings, in which the tree remains were fossilised.

Geological background

Upper Cretaceous volcanic varieties and rare volcano-sedimentary and sedimentary sequences, all part of the Burgas Group (Petrova et al, 1992), are

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exposing in the area of the town of Sozopol. The rocks of the group are Coniacian–Santonian in age and have complex relationships vertically and laterally, and host numerous sills, necks, dykes and comagmatic intrusions (Dabovski et al., 2008).

The Upper Cretaceous volcanic rocks are considered as products of multiple central and linear paleovolcanic structures (Stanisheva-Vassileva, 1980). In places, fragments of deeply denuded apparatuses are preserved, in the central parts of which subvolcanic dykes and small plutonic bodies (volcano-intrusive centers) are revealed.

The Upper Cretaceous volcano-intrusive structure, which is exposed in the coastal area between the Burgas Bay and the town of Primorsko is referred to as the Rosen Paleovolcano, which is not well studied because most of the structure is under the sea level. Nevertheless, it is a paleovolcanoe of central type with a caldera inside. In the present study, we use the term Rosen Paleovolcano in a narrower sense, as a synonym of the Sozopol volcano according to Petrova and Simeonov (1989). According to the adopted scheme, the paleovolcano possesses three elements: an external accumulative part, an internal destructive part (caldera) and a ring-shaped (Rosen) intrusive. The caldera development of the volcanic structure, the Sozopol Caldera, is directly related to the formation of the underwater natural phenomenon *Petrified Forest*. The caldera is exposing along the coastline between Sozopol and St. Agalina Cape, and it consists of lavas, with rare interlayers of block and agglomerate tuffs, which are exposed on St. Ivan and St. Peter islands, as well as on the northern coast of the Old Town of Sozopol.

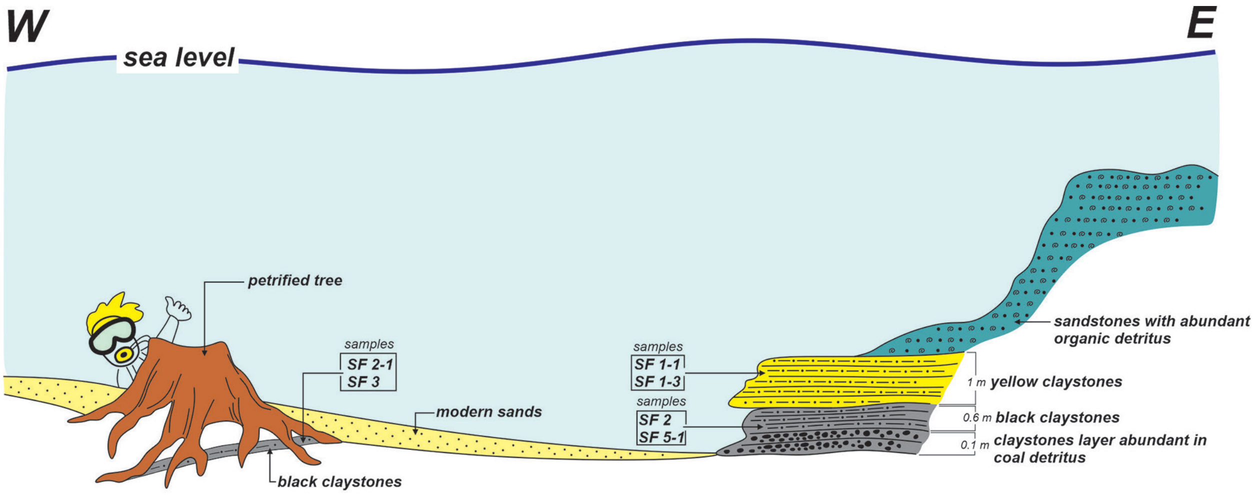
Another exposed onshore unit is the middle–late Miocene Evksinograd Formation, consisting of clays, sands and sandstones (Popov, Kojumdjieva, 1987). The sediments overlay unconformably the varied lava flows and sills and is exposed as a relatively narrow NW-SE elongated strip.

According to Shishkov et al. (1983), the Sozopol Caldera used to be a favourable morphostructure for coal deposition and served to form a sedimentary basin that could be referred to the caldera type. In the initial stage of its development, a freshwater lake was formed, filled with atmospheric waters and clastic sediments, origination from the fence hights. During the following stage, the freshwater lake gradually turned into a submerged, heavily watered swamp, overgrown with moisture-loving subtropical vegetation of type Myscacea-Taxodiacea. Owing to the relatively rapid sinking of the caldera, probably in combination with tectonic processes, a rupture of the protective wall from the north and north-east followed, and a lagoon with a high water salinisation and rapid sedimentation was formed in place of the freshwater basin. The facies setting has turned into coastal-marine as evidenced by the overlying sediments. The peatland was briefly filled with fine- to medium-grained sands, thus interrupting peat formation. Only the stumps of the swamp cedars remained sticking out (Shishkov et al., 1983).

Results

In the eastern part of the studied *Underwater Petrified Forest* site, in the water area between the Old Town of Sozopol and St. Ivan Island is exposing a subhorizontal succession of clays and sandstones (Fig. 1). The described section has an apparent thickness of about 1.80 m and covers Upper Cretaceous volcano-sedimentary and volcanic lithotypes. It is located at a depth of ~20 m. At the base, there is a level of grey-black to black claystones, abundant in charred plant detritus (about 10 cm). This lower level of the section probably covers the petrified trees. Similar black claystones are also found at the base of almost all the well-preserved trees underlying the modern shell sands. Analogous black clayey rocks are also found at the base of almost all the well-preserved trees underlying the modern shell sands (Fig. 1). We assume that this is the coal seam described by Shishkov et al. (1983) covering the fossilised trees. With a gradual transition, grey-black claystones without charred plant fragments cover the coal seam. The total thickness of the black clays is about 60–80 cm. Yellow to yellow-orange claystones with a thickness of about 1 m follow with a rather sharp lithological transition. They are topped by weakly cemented, detritic, calcareous sandstones. These rocks enclose the Sozopol Caldera from east-northeast and limit the *Petrified Forest* in that direction. The described structures are ~3 m thick, or even more in some places. The described section has similar features to sediments from the Alepu beach area (Shishkov et al., 1983).

The claystones from the base of the petrified trees and from the cross section east of the forest look alike macroscopically, but in order to make the comparisons as correct as possible, a Powder X-ray diffractometric assay was made. All analysed samples of clay sediments suggest approximately similar mineralogy of silicates, clay minerals, sulphides, oxides, micas and amorphous products, represented by highly charred detritus (45–49%). Silicate minerals are quartz, orthoclase, albite and diopside, sourced by the Upper Cretaceous volcanic and volcano-sedimentary rocks, comprising the Sozopol Paleovolcano and Sozopol Caldera, respectively. These rocks are also the source of the titanomagnetite found in two of the samples. Most abundant are



X-ray diffraction analysis

sample	description	Qtz	Or	Ab	Di	Timgt	Kaol	Mont	Ilt	Rec	Hly	Ser	mica	Py	amorphous
SF 1-1	yellow claystones	23	18									18,9	9,7		47
SF 2	black claystones	19				2,3	17,8	16,7		16				7,6	46
SF 2-1	black claystones	25	9,8	11,8	3,3	1,4		9,3	13			13,9	9		45
SF 3	black claystones	11	26,4				16,3	13,3			21,3			5,7	46
SF 3-1	yellow claystones	21	15				3,6	15,4				17	8	7,8	49
SF 5-1	black claystones	23	14,7	10,7			7,8	15,6		13,8			10,7	3,8	45

Fig. 1. Schematic cross section of the *Underwate Petrified Fores* (out of scale) and X-ray diffraction analysis. Mineral abbreviations: Qtz, quartz; Or, ortoclase; Ab, albite; Di, diopside; Timgt, titanomagnetite; Kaol, kaolinite; Mont, montmorilonite; Ilt, illite; Rec, rectorite; Hly, halloysite; Ser, sericite; Py, pyrite.

clay minerals represented by kaolinite, montmorillonite, illite, halloysite and rectorite. Kaolinite (3.6–17.8%) and montmorillonite (9.3–16.7%) are the dominant phases (Fig. 1). The yellowish claystones of the upper parts of the section indicate higher content of micas (sericite, etc.).

Conclusions

The described underwater sedimentary succession of clay and sandy sediments, overly the fossilised trees. Unequivocal evidence of this is the level at the base of the rock sequence, abundant in charred plant detritus and high in amorphous (carbonised) matter. X-ray diffraction studies prove significant similarities between the claystones from the section described to the east from the petrified trees, and the black clays found in the roots of the fossilised trees (Fig. 1). Undoubtedly, the underwater rock sequence described for the first time sheds a new light on the study of the underwater *Petrified Forest*. Future studies will aim to establish whether the described underwater outcrops belong to the Euxinograd Formation. Moreover, upcoming research will aim to describe the sedimentary rocks exposed on St. Ivan Island and their relationship with the section described here and the Euxinograd Formation. A correlation will also be made between the rocks on the Alepu Beach (belonging to the Euxinograd Formation), those on St. Ivan Island and the clastic sequence described in this article.

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