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GEOLOGICAL CONDITIONS OF NATURAL H_2 EXPLORATION ON THE BALKAN PENINSULA FOR PROSPECTIVITY MAPPING

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Abstract

Natural hydrogen (H_2), generated by geological processes in the subsurface, is considered a sustainable, low-carbon energy source. In the past few years, exploration activities for H_2 in different countries have increased, and some of the results received have been shared and published. A few published papers are concerning field observation and geochemical studies in the Balkan Peninsula area. The analysis of exploration efforts indicates that most potential sites for H_2 exploration appear to be those with ophiolite associations. The primary purpose of the research is to clarify the possibilities for general prediction and mapping of the H_2 potential in the Balkan Peninsula area. The goal will be achieved based on analyses of previous research experience and its application in the territory of Bulgaria by evaluating existing and obtained geological data, mapping methodologies and approaches, and potential benefits and limitations. The expected results of the current review study will enable the way for regional mapping of H_2 exploration potential areas on the Balkan Peninsula.

Keywords: *Natural Hydrogen, ophiolite, Balkan Peninsula*

1. INTRODUCTION

Natural hydrogen (H_2), generated by geological processes, holds significant promise as a sustainable and low-carbon energy source. The expectations, that this resource would actively answer the purpose in the transition to clean energy are based on the results of active exploration in North America, Asia, Africa, and Australia [1], with significant quantities found in Mali's Baurakebougou field, Albania's Bulqize chromite mine, France's Lorraine mining basin, and Turkey's Chimaera. The discoveries often occur by chance. Effective exploration methods are required to comprehend subsurface processes that control H_2 generation, migration, and trapping. Generally, H_2 observations are linked to water reacting with ultramafic rocks (serpentinisation); water radiolysis; radioactive decay of U, Th, K; deep H_2 sources; thermal maturation of organic matter [2]. Exploration should concentrate on areas associated with serpentinised ophiolite series, mid-oceanic spreading ridges, transform faults, passive and convergent margins, intracontinental rifts, and fault zones. Considering significant quantities of H_2 have been discovered in the Bulqize chromite mine in Albania, it is important to examine the distribution of similar rock associations on a regional scale within the Balkan Peninsula and explore possibilities for their preliminary mapping to assess their prospects. As a foundational approach, it is suggested to trace the "hydrogen window" areas, where some or all mechanisms are present and suitable for modelling.

2. EXPERIMENTAL

As suggested by previous studies [2], preliminary work was undertaken in this research. This work involved a thorough review and analysis of all available data on the occurrence of H_2 and the presence of hydrogen source rocks. This regional-scale evaluation was instrumental in identifying and defining a prospective area for exploration. The Balkan Peninsula's geological environments and geotectonic settings play a key role in understanding the behaviour and evolution of the region.

Previous studies [3, 4, 5] highlight notable similarities in emplacement mechanism and characteristics typical of the Tethyan ophiolites (obduction) type of geotectonic settings [6], which occur when oceanic crust lithosphere, formed in a fore-arc or back-arc, known as a supra-subduction zone (SSZ) setting, is obducted over a continental passive margin that has failed or is failing to subduct (Fig. 1A). The analysis indicates that most potential sites for H_2 exploration appear to be those with ophiolite associations. The Tethyan obduction type highlights promising ophiolite associations for H_2 exploration on the Balkan Peninsula, shaped by the subduction-collision dynamics of the Eurasia and Apulia plates and the extensive Vardar-Izmir-Ankara suture [3]. Extending from west to east, several ophiolite complexes have been identified that share similar features (Fig. 1 B) and geographically cover the territories of Albania, Kosovo, Bosnia and Herzegovina, Serbia, Greece, Turkey, and Bulgaria.

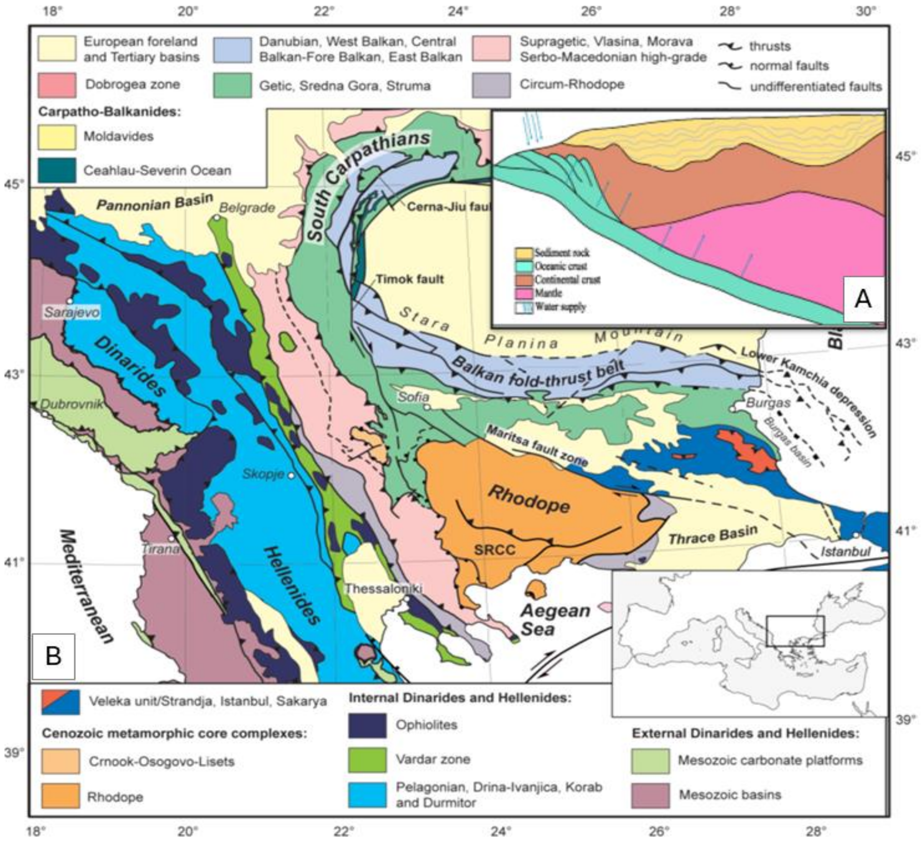

Figure 1. Natural hydrogen potential ophiolite complexes in the Balkan Peninsula: A) Tethyan ophiolite obduction zone type geotectonic setting, modified after [6], B) Tectonic map, modified after [7]

3. RESULTS AND DISCUSSION

Ophiolites are found in the Dinarides, the Vardar zone, the Circum-Rhodope belt, around the periphery of the Rhodope massif, as well as to the south of the Rhodopes - specifically on the island of Samothrace, along the lower reaches of the Maritsa River, on the island of Lesbos, and south of the Dardanelles on the Biga Peninsula in NW Turkey. To the east, they continue into the Tavshanli zone, located south of the Vardar-Izmir-Ankara suture.

3.1 Dinaride ophiolite belt

This ophiolite belt [4] was partly generated above a subduction zone and represents a subduction complex controlled by tectonic accretion and sedimentary reworking in fore-arc basin settings. The metamorphic soles of the Dinaride ophiolites formed during the Middle–Late Jurassic Age. A possible cause for the formation of the Dinaride ophiolites is the collision of a subduction trench with a continental margin. Generally, subduction in a northward direction caused ophiolite formation in the SSZ during the Late Cretaceous. During the Upper Jurassic, ophiolites were obducted, which are observed on underlying Triassic and Upper Jurassic carbonates and are transgressively overlain by Tithonian and Lower Cretaceous terrigenous rocks.

3.2 Ophiolites of the Western Vardar zone

Studies [8] in Albania and Kosovo show that the main structures in which H_2 leakage from natural springs has been detected are related to the Western Vardar ophiolites. In the region of Albania, the Western Vardar ophiolite is represented by the Mirdita ophiolite, located in the Albanides mountain belt, which is in the Dinaride-Albanides-Hellenides segment of the Alpine orogenic system, and interpreted as derived from an SSZ. The ophiolites are of Middle Jurassic age and were formed during the beginning of the closure of the Neo-Tethys, as a result of the subduction of the Adria plate under the Eurasian plate. Some rocks from the ophiolite mélange trace the beginning of the obduction to the Late Jurassic. These are mainly lenticular serpentinite bodies ranging in size from 10 to 100 m. They are mostly deformed and folded. Peridotites and dunites, metagabbro bodies and diabase dikes are rare. The Upper Jurassic (155–150 Ma) ophiolite complex was covered by Tithonian and Lower Cretaceous sediments. The complete closure of the basin occurred between the Late Cretaceous and the Paleogene, leading to the formation of the Sava suture zone. The Bulqize mine is situated within the Jurassic ultramafic Bulqize massif, where H_2 is produced from depths of up to 1000 m. This occurs in a highly fractured zone through which water seeps from the upper levels of the mine. This water, along with meteoric water, contributes to the serpentinisation process.

3.3 Ophiolites of the Eastern Vardar zone

The Eastern Vardar Ophiolite Zone (EVZ) in the Pannonian Basin has two branches: one bends west from Fruška Gora, while the other extends northeast to Transylvania [7]. EVZ overlies the Tisza-Dacia mega-unit further north [5]. In the Belgrade surroundings, EVZ's oldest layers include Upper Jurassic deepwater claystones and radiolarites associated with syndepositional basalts, serpentinized peridotites and ophiolitic melange with fragments of serpentinites, diabases, limestones, claystones, and cherts. The eastern boundary features complex tectonic structures, with Serbomacedonian metamorphics to the east and EVZ formations to the west. During the Upper Tithonian, EVZ ophiolites were obducted eastward over the Serbomacedonian unit, later moving west-southwest as part of a forearc basin [7]. Both zones of ophiolites in the Dinarides (i.e. Dinaride Ophiolite Zone and Ophiolites of Western Vardar Zone), along with the ophiolites of the Eastern Vardar Zone, all contain ophiolitic melanges with similar ages of fragments beneath the obducted ophiolites.

3.4 Balkan-Carpathian ophiolite segment

The Balkan-Carpathian segment [9, 10] consists of a complex assembly of lower-grade ophiolite massifs across Romania, Serbia, and Bulgaria, with an origin corresponding to a mid-ocean ridge setting, with the protolith estimated to date back to 563 million years ago. Key ophiolite massifs within this segment include Tcherni Vrach, Zaglavac, Deli Jovan, and South Banat, featuring structures like pillow lavas, pyroxenites, and gabbro-porphyrite dikes. These ophiolites, shaped by ocean floor metamorphism and obduction alongside an island-arc association in the subduction zone, highlight intricate geological processes. Stratigraphically, the ophiolite formations in NW Turkey exhibit similarities to those found within the Balkan-Carpathian region [9]. The South Banat ophiolite massif, located at the northwestern edge of the Carpathian-Balkan segment, is thought to predate the Early Caledonian period and comprises two main rock types: ultramafic tectonites and cumulative gabbros mingled with ultramafic rocks throughout the ophiolite profile.

3.5 Circum-Rhodope belt

In the Circum-Rhodope belt, also known as the innermost Hellenic ophiolite belt, various rock materials are observed as an incomplete ophiolite sequence [3]. The same age (Jurassic-Cretaceous) is also found in the ophiolites of the Circum-Rhodope zone from the outcrops in Northern Greece and those in Western Thrace, which are exposed beneath the Tertiary sediments or tectonically cover the Rhodopean high-grade metamorphites. They are in Makri, Maronia, Drymos–Melia, Mikron–Derion, Mandritsa–Metaxades, Agriani and Didymotychon, and are united in the Evros ophiolite complex. These rocks, along with associated low-grade volcanic and sedimentary materials, are considered part of the Circum-Rhodope belt. The Circum-Rhodope Belt of northern Greece is metamorphosed and is tectonically emplaced eastward on the Serbo-Macedonian Massif during the Late Jurassic, probably by obduction [7].

3.6 Rhodope ophiolite association

The metamafic rocks exposed in the metamorphic basement of the Rhodope Massif are supposed [11] to form a Rhodope ophiolite association, developed concurrently with primary rock formation and subsequent metamorphism. The association consists of three main complexes: a) metavolcanites, b) metaintrusives, and c) metaserpentinites. Geochemical analysis suggests an SSZ origin for metabasites, which aligns with the characteristics of the exposed metasediments. The broader geological setting of this ophiolite suite, along with its associated sedimentary sequences, represents obducted ophiolites deposited onto the ancient terrain of the Rhodope Massif, closely connected to the Vardar Ocean.

4. CONCLUSION

The examination of the geological conditions for exploring natural hydrogen within the confines of the Balkan Peninsula reveals that ophiolite zones and segments are prevalent. They belong to a single type of obduction – Tethyan, which can serve as a basis for mapping and tracing the areas of “hydrogen windows”.

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