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Original Research

Travertine and Mid-Ocean Ridges Are Related Analogues Regarding Geographical Location and Sedimentary Model

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Abstract

The rise of the mantle asthenosphere and tectonic activity are linked to travertine and mid-ocean ridges, although their relationship has not been clarified. To investigate the connection between travertine and mid-ocean ridges, we gathered information on the geographic distribution of travertine from around the world, plotted it, and linearized it. Making a map of the locations of linearized travertine, mid-ocean ridges, and 2016-2020 (M>5) earthquakes (which may or may not constitute seismic belts) and assessing its global distribution. The sedimentary models of travertine and mid-ocean ridges, on the other hand, were drawn based on previous studies, comparing and analyzing the similarities and differences between the sedimentary models of travertine and mid-ocean ridges. The results indicate that: 1) travertine and mid-ocean ridges are both primarily distributed in the seismic belts, 2) their deposition is closely related to the mantle asthenosphere, and 3) travertine occurs on land but mid-ocean ridges are in the ocean, which is a significant difference. This study examines the relationship between travertine and mid-ocean ridges are related analogs regarding geographical location and sedimentary model and suggests that travertine, like mid-ocean ridges, may be a driving force for plate drift. Researchers may gain a better understanding of the otherwise difficult-to-study mid-ocean ridge system by analyzing similarities between travertine and mid-ocean ridges.

Keywords: travertine, mid-ocean ridge, mantle plume, tectonic activity, sedimentary model

Introduction

Travertine and/or tufa have the ecological and engineering value of water storage and drainage due to their loose and porous structure. Its vibrant colors and clear water make it a popular tourist destination. It has the scientific research value of paleoenvironment and paleoclimate records due to the layered and zonal structure formed by periodic sedimentation. As a consequence, it has piqued the interest of academics. Travertine and/or tufa is a carbonate that

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is formed when CO_2 gas escapes from supersaturated fluids and precipitates [1, 2]. Due to differences in sources of carbon dioxide, it can be divided into two classification types, one from the atmosphere or soil, which is called Tufa (Meteore travertine), and the other from the degassing of mantle magma, which is called Travertine (Thermogen travertine) [3-5]. Travertine deposits and volcanism are often closely associated due to processes such as hot crustal-fluid flow, active tectonism, and related surface hot springs [6, 7]. Carbonate is a common constituent of magma, and during magma upwelling, pressure reduction leads to outgassing and eventual release of CO_2. Strong geological tectonic activity [8-10] (such as earthquakes) cause cracks in the Earth's crust, which then provides a channel allowing the rise of mantle asthenosphere and CO_2.

Mid-ocean ridges (MORs), also known as spreading oceanic ridges, are the edges of the oceanic plates that are extending (Fig. 2b). The Eastern Pacific Rise, the Mid-Atlantic Ridge, the Mid-Indian Ridge, and the Gakkel Ridge in the Arctic Ocean are among the modern mid-ocean ridges, which span 8,000 kilometers and cut through four oceans (the Atlantic, Pacific, Indian, and Arctic seas) [11]. MORs are mountain ranges that rise from plate fractures in the ocean following decompression and melting of the mantle asthenosphere [12]. Plate tectonic motions are commonly considered to be driven by slab pull at subduction zones and ridge push at MORs, with motion punctuated by plumes of hot material rising from the lower mantle [13-16]. Those motions provide a driving force for "continental drift", which is an important component in the theory of "Plate Tectonics". MORs are Earth's most important producers of igneous rocks, contributing ~75% of Earth's present-day volcanism [17], therefore, it is often associated with tectonic activity.

Above all, the formation of the mantle asthenosphere and tectonic activity are linked to both travertine and MORs. Their formation processes are clearly identified. This study made the creatively claim that travertine and MORs are analogous in some way. The relationship between the geographical distribution of the three is contrasted and examined by classifying the geographical distribution data of global travertine, MORs, and seismic belts. Additionally, the similarity of the sedimentary models of travertine and MORs are examined, as well as their sedimentary model illustrations. Therefore, we hypothesize that travertine, like mid-ocean ridges, may be a driving force for plate drift based on the link between travertine and these structures. By comparing similarities between travertine and mid-ocean ridges, researchers may be able to better comprehend the otherwise challenging mid-ocean ridge system.

Material and Methods

First off, we discovered that the geographical distribution data of travertine was sorted out in our previous research [18] and Ricketts et al [19] almost cover the geographical distribution data of all travertines in the world (a total of 1,699 places) after conducting searches on China national knowledge infrastructure (CNKI, https://www.cnki.net/) and Web of Science (WOS, https://www.webofscience.com) using the keywords "travertine" and "mid-ocean ridges". Therefore, we regard the data gleaned from these two works of literature as the spatial distribution of travertine on a global scale. Data on the geographic distribution of earthquakes with a magnitude of 5 or higher from 2016 to 2020 were also acquired at the same time from the United States Geological Survey website (USGS, https://earthquake.usgs.gov/earthquakes/search/). The spatial distribution data for travertine and earthquake was processed and shown using ArcGIS software and the figures were edited in Photoshop. The linearized seismic geographical distribution data can in some ways be viewed as seismic belts. To compare their geographic similarities, the linear maps of travertine, mid-ocean ridges, and seismic zones are created on the same map. Secondly, in order to compare the two sedimentary models, we modified the sedimentary models of travertine and mid-ocean ridges based on prior research. Fig. 1 displays the method of research.

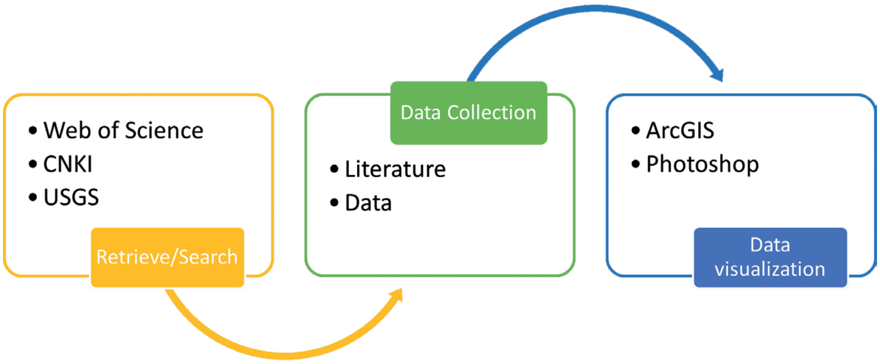

Fig. 1. Geographical distribution data collection phases for analysis.

Results

Travertine and MORs Are Geographically Located in Seismic Belts

We looked into the mechanisms that led to the location of MORs and travertine in regions with a high frequency of earthquakes because they are found in active regions of the geological structure. We gathered the geographic data of earthquakes with M>5 from 2016 to 2020 available from the USGS instead of the frequency of M≤4 earthquakes, which are too frequent to have any discernible impact on travertine deposition [8]. The seismic zone, which is often referred to as the distribution of earthquakes globally, was mapped using USGS data (Fig. 2a). Next, the distribution of the global data on travertine formation from the previous study was mapped (Fig. 2b). Finally, the location of the MORs is established from earlier research [20-22], and the travertine and seismic distribution zones are identified (Fig. 2c). After gathering data using the aforementioned methods, Figure 2 is created. Where (a) shows the seismic zone (M>5) distribution map from 2016 to 2020, (b) the travertine distribution map globally, and (c) the linearized travertine, mid-ocean ridges, and seismic zones distribution map.

Fig. 2 analysis yields the results shown below. The seismic belts are distributed along the continental line in the Pacific Ocean, denoted as "S" in the Atlantic Ocean and "λ" in the Indian Ocean (Fig. 2a). Travertine is mainly distributed across North America, Europe, and Asia (Fig. 2b). Fig. 2c) depicts the distributions of travertine and earthquakes as lines, along with the distribution of MORs for direct spatial comparison. Both the distribution of travertine and MORs coincide with the location of the seismic belt, that is, the travertine ridge and mid-ocean ridge lines are distributed in the seismic belt. Only a portion of the Pacific seismic zone does not share distribution with travertine or MOR (Fig. 2c).

The Sedimentary Model of Travertine and MORs Are Similar

MORs and travertine are similar in terms of their sedimentary models, in addition to their geographic locations. Both of them were deposited after rising and cooling through distinct routes and were derived from the mantle asthenosphere. The deposition model of the mid-ocean ridge and travertine was created using the study of Whittaker et al. [22] and Keane [23] in addition. This model is depicted in Fig. 3. The black arrow in this diagram denotes the asthenosphere's upwelling direction.

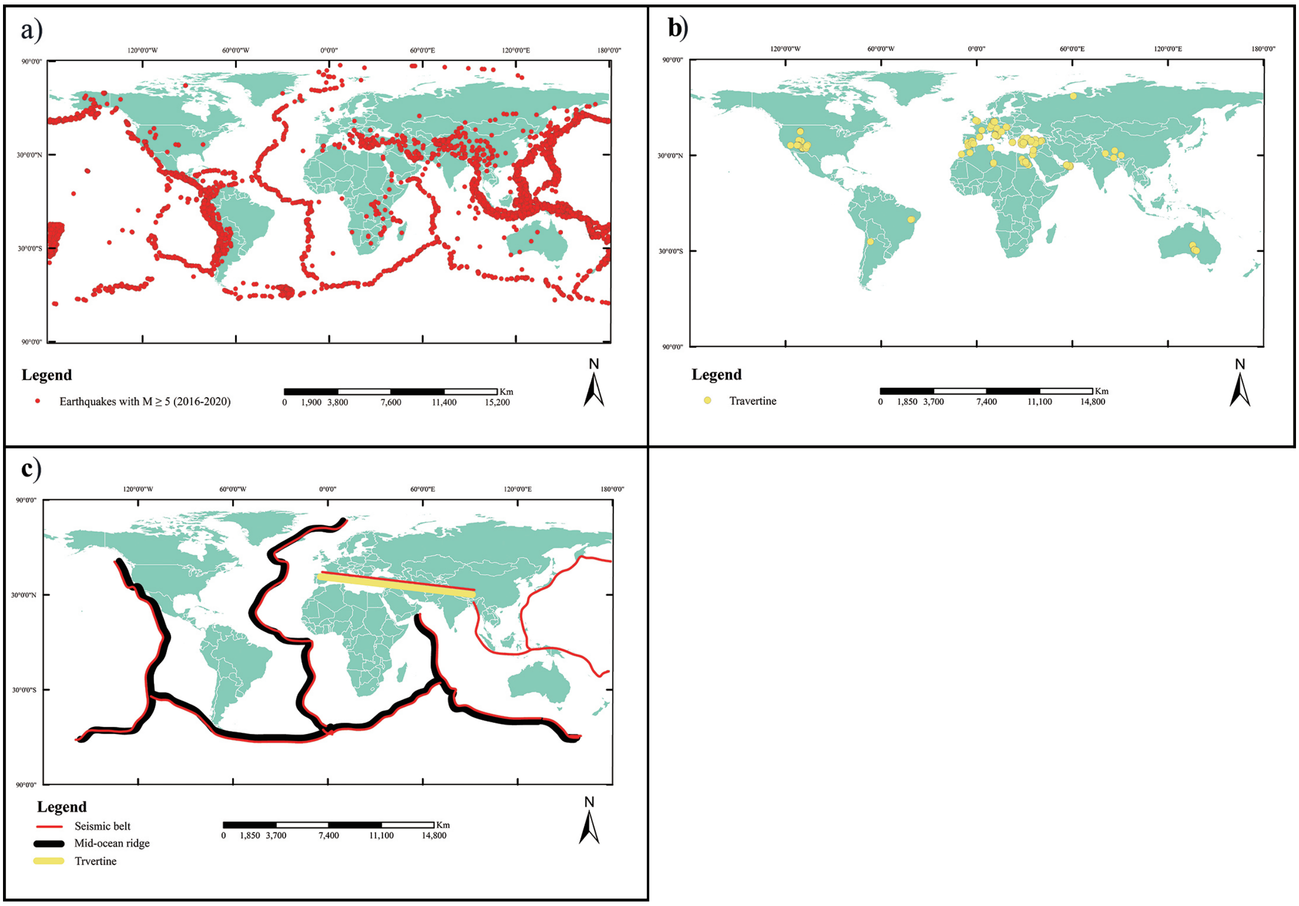

Fig. 2. Geographical location map.

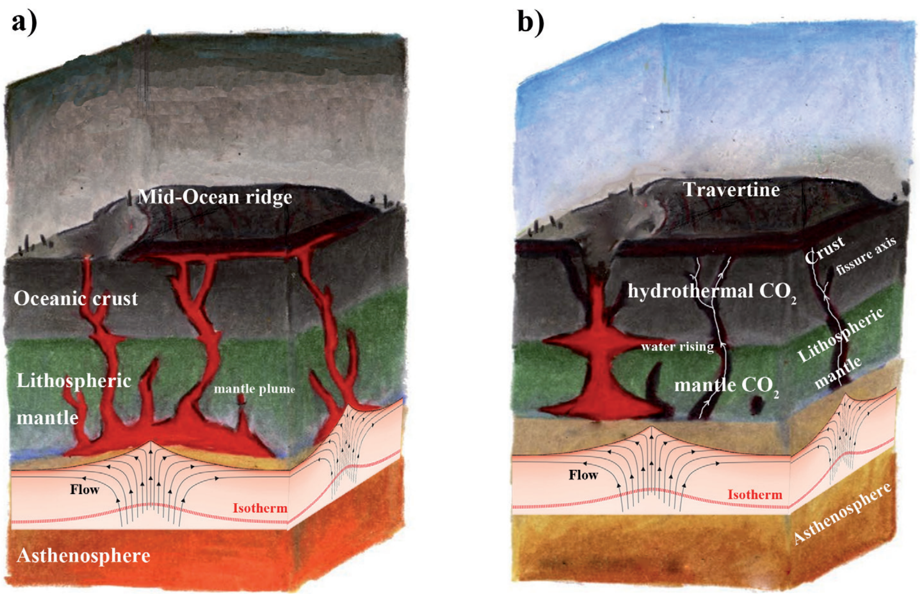

Fig. 3. Sedimentary models.

Table 1. Travertine and mid-ocean ridge sedimentary models.

Sort	Travertine	Mid-ocean ridge
Rock types	Limestone	Basalt
Position of deposition	On land	Bottom of the ocean
Upwelling channels	Fissure axes	Mantle plume
The original material	Noncondensable CO_2 etc	Asthenosphere

Fig. 3 analysis yields the results shown below (Table 1). The theory of plate tectonics describes subduction zones and mantle plumes (hotspots) as distinctive elements of mantle convection [24]. These plumes have an immediate impact on MORs because they provide them with material and have an impact on the temperature beneath the MOR as well as the basalt composition of the MOR. The majority of observed large igneous provinces are formed in this region. Plume material will preferentially flow laterally towards areas of elevated lithosphere-asthenosphere interfaces (that is, beneath MORs), which stabilizes the MOR segment and stays proximal to the plume via ridge jumps [12, 22, 25] (Fig. 3a). Carbonate ions required in travertine deposition come from large amounts of noncondensable CO_2 transported from lithospheric mantle magmatic, metamorphic and geothermal systems to regional aquifers through fissure axes [26-30]. Meanwhile, hydrothermal waters feed into extensional fissure axes and deposit successive layers of carbonate as fissure travertine [8]. The carbon dioxide is then released from the mantle and is dissolved in the water in the fissure, where it upwells to the crustal surface, and is finally combined with Ca^{2+} to deposit into travertine (Fig. 3b).

Discussion

We propose a general connection between travertine formation on plate boundary volcanoes and ridges forming on the ocean floor near spreading centers. Based on the shared influence of tectonic activities on the formation of travertine and MORs, their similarities in their geographical location and sedimentary model are analyzed. The first major difference observed is that one occurs on land while the other occurs at the bottom of the sea (Fig. 2c). Additionally, the sedimentation of travertine requires only part of the rising material of the mantle asthenosphere, while the MOR requires the entirety of the rising plumes. The purpose of exploring the relationship between travertine and MOR is: Firstly, we know that the MOR is located in the deep sea, which makes it difficult to sample, monitor, and study [31]. Therefore, finding a suitable analog may greatly improve our ability to study MORs. Secondly, in the theory of plate tectonics, the formation of MORs provides a driving force for continental drift. If the dynamic similarity between travertine and MORs can be identified, the dynamic estimation study generated by MOR expansion may be equivalent to travertine ridge expansion, leading to a better understanding of MOR expansion dynamics. Thirdly, we observe that MOR and travertine are located in the marine seismic zone and land seismic zone respectively. However, MOR is not found on the left edge of the Pacific seismic zone. But there is a giant low-velocity anomaly shaped like an iron, which is small at the top and large at the bottom and narrow in the north and wide in the south. The giant low-velocity anomaly is 85 to 250 kilometers underground and about 160 kilometers thick [32] (Fig. 2c). Fourthly, as the current study only investigates the apparent similarity between travertine and MORs, further comparative studies are needed to better understand the underlying similarities in their geology, geochemistry, and geophysics. For instance, mass spectrometer analysis and testing techniques like MC-ICP-MS (Multi-Collector inductively coupled plasma mass spectrometer) and TIMS (Thermal ionization mass spectrometry) were used to further the similarity examination of the isotopic composition of transverse and mid-ocean ridges.

Conclusions

In this study, the geographic distribution data of seismic zones, mid-ocean ridges, and global travertine are compiled, visualized using appropriate professional software, and their geographic distributional commonalities are examined. The sedimentary models of the travertine and the mid-ocean ridge are also presented, and their similarities and differences are compared based on earlier studies. The following are the primary conclusions:

- Geographically, travertine can be found mostly in North America, Europe, and Asia (Fig. 2b). The Atlantic Ocean and the Indian Ocean, respectively, are covered with "S"-shaped and "λ"-shaped mid-ocean ridges. It is vital to remember that the mid-ocean ridge and the travertine are both situated in seismic zones.
- The travertine and mid-ocean ridge sedimentation models are comparable. Both of them came from the mantle asthenosphere, and after upwelling through certain routes, they gradually cooled and deposited. However, they differ in that all of the asthenosphere material is utilized to create mid-ocean ridges, whereas the travertine requires only a portion of the mantle material (such as escaping CO_2 and potentially other minerals). Another distinction is that the asthenosphere material that makes up the mid-ocean ridge rises in the mantle plume, whereas the material that makes up the travertine rises in the fissure axis.
- We propose a generic link between ridges forming on the ocean floor at spreading centers and travertine forming on plate boundary volcanoes. The rationale is that travertine may provide a driving force for plate drift and thus, similarities between ocean ridges and travertine should be studied. There is a difficulty because there are no data or analytical methods used to test the claim. We will have a deeper comprehension of the interactions between the physical and chemical processes occurring at various plate boundaries. For instance, to further the similarity investigation of the isotopic composition of transverse and mid-ocean ridges, mass spectrometer analysis and testing methods like MC-ICP-MS and TIMS were applied.

Acknowledgments

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Conflict of Interest

The authors declare no conflict of interest.

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