IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

Comparative Study of Columnar Joints: Insights from Mars and St. Mary's Island as a Terrestrial analogue

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Abstract: Columnar jointing, a geological feature commonly observed in various rock formations on Earth, is rare and sparsely distributed on Mars. Identifying such structures on Mars, particularly those formed through interactions between lava and water, could provide valuable insights into the planet's history of near-surface water. This research focuses on the columnar jointing within the Marte Vallis Crater, where mafic lava and liquid water may have interacted over extended periods ranging from several years to decades. By examining terrestrial analogues, such as the Madagascar flood basalt province and the St. Mary's Island (SMI) volcanics, which are linked to volcanic activity during the breakup of Greater India and Madagascar in the Upper Cretaceous (88 Ma), we aim to draw parallels that can enhance our understanding of Martian geologic processes. This study highlights the importance of terrestrial analogues in planetary science and offers new perspectives on the potential for past liquid water on Mars, contributing to the broader search for habitable environments beyond Earth. This study aimed to explore the similarities between the columnar jointing on Mars, particularly in Marte Vallis, and the well-preserved columnar basalts on St. Mary's Island.

IndexTerms **- Mars analogue, Columnar joint, flood basalt, Marte Vallis, St. Mary Island.**

I.INTRODUCTION

Columnar basalts serve as evidence of past lava-water interactions, providing terrestrial analogies to help comprehend comparable processes on Mars. [1]. HiRISE found multi-tiered columnar jointing on Mars. In areas with inferred histories of flood volcanism, the lavas that cooled in the presence of water depended on the specifics of joint formation and occurred in the uplifted walls of impact craters. These are interpreted as columnar basalts based on the local geologic history [2]. Numerous locations on Mars have seen the observation of additional columns since the discovery [3]. The separation is thought to have begun during or soon after a recognized episode of Late Cretaceous basic and felsic magmatism from Madagascar. Numerous plate reconstructions suggest a strong connection between Madagascar and Greater India from the late Precambrian to the Cretaceous eras [4]. Although comparable Cretaceous volcanism is not extensively known from western India, the western edge of India likely rifted off the eastern edge of Madagascar during this late Cretaceous break-up episode. The acid volcanic rocks of the St. Mary's Islands and the mafic dykes of mainland southwest India are two potential outliers [5, 6].

1.1 Geological Setting

In the South Kanara district of Karnataka, St. Mary Island is situated roughly 6 km to the northwest of the port of Maple and 670 km to the south of Bombay. At 130 28' latitude, the St. Marys Islands group of Udupi Islands is positioned almost exactly parallel to the coast. The island has a total area of roughly 500 meters (1640.77 feet). The islands aligned north-south form a noncontinuous chain. The St. Marys Islands are a group of small islands that stretch roughly 6 kilometers off the western coast of central India, close to the seaside community of Maple. The islands are oriented NW- SE. All of the felsic volcanic rocks found on the islands are flat-lying and undeformed; these rocks include dacites and rayodacites[7,8]. some of which have remarkably developed columnar jointing. The St. Marys Islands group consists of four significant islands: North Island, Coconut Island, Darya Bahadurgari Island, and South Island. Of the four islands, the northernmost island, St. Marys Islands, contains a hexagon-shaped basaltic rock formation—the only one of its kind in India [9,10].

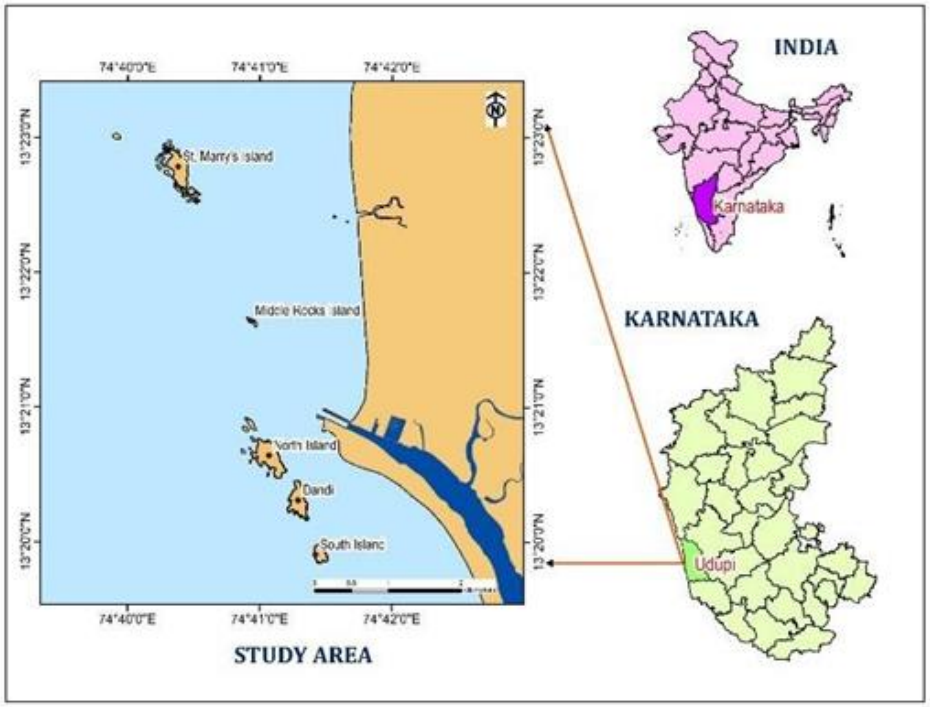

Fig.1.Study Area of St Mary's Island (SMI).

The Karnataka state government donated the island to the Geological Survey of India, which designated the rocks as a national geological monument due to their exceptionally well-developed columnar joints. The island is roughly 500 meters (1640.4 feet) long and 100 meters (328.1 feet) wide. The farthest island from the coast, Coconut Island, is located roughly 2.5 kilometers west of the mainland. The two northern islands, Northern Island and Coconut Island, are larger than the other two and have roughly identical areas (0.14 km2 and 0.13 km2, respectively). At approximately 11.38 meters on Coconut Island, 16.6 meters on North Island, and 11.5 meters on Darya Bahadurgari Island, the topography rises above the present-day sea level [11]. Marte Vallis, located between 170-190 ° W longitude and 0-20 ° N latitude, is a region characterized primarily by channels of possible fluvial origin [15].

II. Data and Sources of Data

The High-Resolution Imaging Science Experiment (HiRISE) on the Mars Reconnaissance Orbiter (MRO) discovered multi-tiered columnar jointing on Mars [2]. For this study, we choose PSP_007341_2020, PSP_006774_2020 Marte Vallis Lat:21.6^0 Lon:184.3^0, credited to NASA/JPL-Caltech/Arizona publicly access. For Fig.1.SMI Map Georeferenced using RS & Arc GIS software.

III. RESEARCH METHODOLOGY

3.1 Geomorphology of St Mary's Island

The St. Mary's islands were sub-aerial as Madagascar was still attached to India. The rifting of Madagascar from India took place around 88 M.Y [9,10]. The landforms in the study area are primarily of depositional nature. The volcanic activity which gave rise to the St.Marys Islands was sub-aerial in nature as that of in Madagascar was still attached to India. The topography of the island is highly irregular and rugged and the islands, except the coconut islands are mainly rocky. Coconut Island has a maximum elevation of 10m above mean sea level compared to the other Islands, which is greater. The Coconut Island has a patchy layer of wave-worn rhyodacite pebbles and cobbles covering the +3m surface. To the west of the pebble bed is the shell deposit, of nearly at 2.5m is observed. Most parts of the Coconut Island most have an elevation of about 6m which represents a dissected marine terrace. St.Marys has just a few coconut trees for vegetation. There are several morphologies identified in the field i.e. columnar basalt [12,13,14].

3.2 Formation of Columnar Lavas

Fig.1.Study Area of St Mary's Island (SMI). Fig.2.Columnar Basalts in SMI. Fig.3. Columns seen in the wall of the impact crater in the Marte Vallis between Elysium and Amazonis planitia. Observation ID: 2020(NASA/JPL-Caltech/Arizona) II. PSP 006985 Formation of Columnar Lavas In terrestrial lavas, narrow (less than a meter to several meters wide), constant-width colonnades form when still-hot lavas are inundated by liquid water [7]. This inundation greatly increases the cooling rate compared with conduction alone, causing rapid contraction of the nearly solid lavas, which results in stress fracturing perpendicular to the cooling front. The spacing of the contraction fractures (joints) is inversely proportional to the cooling rate [8].

Fig.2.Columnar Basalts in SMI.

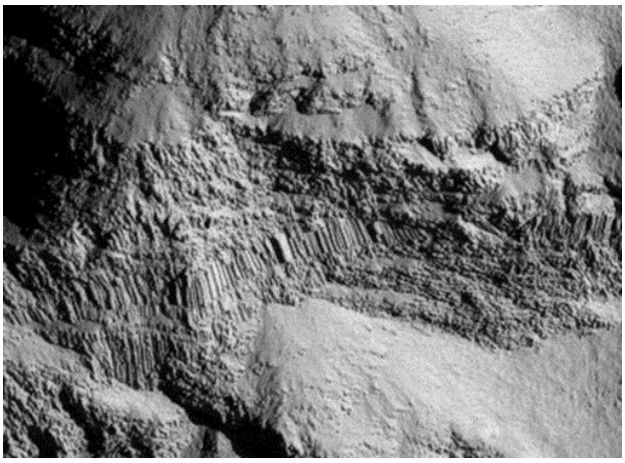

Fig.3. Columns seen in the wall of the impact crater in the Marte Vallis between Elysium and Amazonis planitia. Observation ID: PSP 006985 2020(NASA/JPL-Caltech/Arizona)

3.3 Comparison of the Models

3.3.1 Morphology of Columnar Joint on Mars

The volcanic activity, in the form of flood basalts and long lava flows, utilized the channels to transport lava distances as great as five hundred kilometers or more [16] flows share many similar characteristics of long, terrestrial-like basaltic flows Columnar jointing often forms when basalt lava cools [17,18]. The Columnar Joint occurs in the uplifted wall of the uneroded impact craters on Mars [1].

Fig.3. PSP_007341_2020 Marte Vallis Lat:21.6^{0}Lon:184.3^0(NASA/JPL-Caltech/ Arizona)

Fig.4. PSP_006774_2020(NASA/JPL-Caltech/Arizona)

IV. RESULTS AND DISCUSSION

Lava flow emplacement is a fundamental geologic process on Mars and other planetary bodies. By morphological comparison studying the surface morphology of lava flows The study area exhibits distinct geomorphological characteristics, particularly on St. Marys Island, where features like high beach deposits and wave-cut terraces suggest ongoing uplift processes. The island's geological composition is predominantly acidic, with basic regions also present, including formations such as granophyres, dacites, rhyodacites, and rhyolites. Notably, each major island within the St. Mary Islands group displays a unique rock type, with

Coconut Island stands out due to its well-developed columnar joints. The sediments on Coconut Island consist primarily of medium-sized sand particles, ranging from coarse to fine grains. Interestingly, despite being collected from both the northern and southern edges of St. Marys Island, the sediments share almost identical characteristics across the entire area [11].

V. CONCLUSION

•This study explored the similarities between the columnar jointing on Mars, particularly in Marte Vallis, and the well-preserved columnar basalts on St. Mary's Island.

•Our analysis revealed striking morphological parallels, suggesting that similar geological processes may have occurred on both Mars and Earth. The identification of columnar jointing on Mars not only enhances our understanding of Martian volcanic activity but also provides valuable clues about the planet's past interactions with water.

•These insights are critical in the ongoing search for evidence of habitable environments on Mars.

•While this study provides significant insights, further research is needed to confirm the presence of similar geological features across different Martian regions. Future missions with advanced imaging and sampling capabilities could offer more detailed data, enabling a deeper understanding of Mars's volcanic history and its implications for past water activity.

IV.ACKNOWLEDGMENT

I would like to thank NASA/JPL Caltech/Arizona for HiRiSE image of Mars.

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