Proceedings of the 10th International Conference on Civil Structural and Transportation Engineering (ICCSTE 2025)
July, 2025 | Imperial College London Conference Center, London, United Kingdom
Paper No. 235
DOI: 10.11159/iccste25.235

Geological Formations of the Southern Indian Ocean Islands

Rajeshwar Goodary[1], Andriantahianjanahary Moranydo[1], Mahen Conhyea[2],
Domoina Radaniela Andrianoro[1]
[1]Université des Mascareignes, Mauritius
Avenue de la Concorde, Roches Brunes, Rose Hill, Mauritius
rgoodary@udm.ac.mu; naandriantahainjanahary@student.udm.ac.mu; aoadaniela@student.udm.ac.mu
[2]Gamma Materials Ltd
1st Floor, Le Hub, Industrial Zone, Phoenix
mahen.conhyea@gml.mu.

***Abstract* -** The Gondwana breakup approximately 65 million years ago is the point where Africa, Asia, Australia and South America were separated in different continents. Then, a series of volcano eruptions is the origin of the Indian ocean islands. Mauritius, Reunion island and Rodrigues are located in the same zone and are subject to similar geographical and geological conditions. This series of flood basalt eruptions occurred at different times, with Réunion forming around 60 million years ago, Mauritius about 10 million years ago, and Rodrigues approximately 2.5 million years ago. The soil properties depend mainly on their degree of weathering, beside their mineral composition which also counts for their characterization. This paper focuses the engineering properties of Mauritius and its surrounding sister islands of volcanic origin. Mauritius is made of residual basaltic soil, latosol covering the whole island and dark magnesium clay in some regions. Engineering projects are challenged by different natural hazards affecting the area. The study of landslide occurrences and other hazards helped to identify the zones of highest risks and establish a comparison of georisks between Mauritiusand the other islands. Expansive soils occurring in West and South-West regions of Mauritius, pose considerable challenges to civil engineering professionals due to their tendency to swell when wet and shrink when dry, leading to damage to structures and infrastructure. Soil stabilization strategies are used to resolve these challenges, with lime stabilization being the most common option in Mauritius. This procedure improves the engineering qualities of problematic soils by decreasing plasticity, increasing bearing capacity, and improving compaction characteristics. Lime treatment for expansive dark magnesium clay shows up to a 10 times improvement in California Bearing Ratio (CBR) values, significantly improving its load-bearing capacity. This study clarifies the historical context of the Indian Ocean region by examining the geological evolution of the Mascarene Islands, the geomorphology of Mauritius, and the characteristics of its various soils, therefore highlighting the dynamic processes that have moulded its unique landscapes.

***Keywords*:** Gondwana breakup, Mascarene Islands, Mauritius, Volcanic Island formation, Expansive soils, Soil Stabilisation.

1. Introduction

Indian Ocean islands' geology is interlinked with plate tectonics and volcanism that changed the pattern of the earth over millions of years. The Indian Ocean and its landforms appeared 65 million years ago as a result of the Gondwana supercontinent fragmentation [1]. These processes created the Mascarene Islands comprising Mauritius, Réunion and Rodrigues islands.

Mauritius was founded 10 million years ago as a result of a series of volcanic activities which shaped the island [2]. Four volcanic processes created the island's geomorphology which, over millions of years went through natural weathering processes to generate different soil formations. The island's volcanic origin can also be revealed in the components of the residual basaltic soils comprising mainly Latosols and Dark Magnesium Clays [1], the latter belonging to the montmorillonite clay family. These soils are essential to understanding the geological evolution of the island, but expansive Dark Magnesium Clay poses challenges for engineers [9].

For the purpose of this study, soil samples have been taken from various strategic geological locations in Mauritius. The soils occurring at Baie du Cap, La Butte and Tamarin have expansive properties that swell and shrink at different seasons. These soils have long been considered as geotechnical risks because of their potential to damage and even destroy infrastructure [8]. Other geo-hazards including landslides and slope instability are also a potential threat and addressing these issues is essential for a sustainable development strategy on the island. The study also examines the geology of the other Mascarene Islands in the Indian Ocean and their behaviour compared to those of the native soils occurring in Mauritius [3]. The research focuses on the history of these islands and explores ways to stabilize the expansive soils.

2. Indian Ocean islands formation

Gondwana is the landmass that grouped South America, Africa, Antarctica, Australia, Zealandia, Arabia, and the Indian Subcontinent which broke up around 65 million years ago and eventually four continents are now distinguished which are separated by the Indian and Atlantic Oceans. India detached from Africa and became part of Asia continent. Australia and Madagascar became independent islands in the Indian Ocean.

Iegupov et al. [1] summarized the formation of the islands in Indian Ocean and Mauritius. Sequential eruptions of volcanoes which occurred 60 million years ago gave rise to the Reunion Island with continuous volcanic activity on Piton de la Fournaise, presently active. The same volcanic hotspot caused the formation of Mauritius 10 million years ago and Rodrigues 2.5 million years ago.

The island of Mauritius emerged from four volcanic phases, namely:

1) Emergence of the Island (occurred 10 – 6.7 million years ago). It is the first eruption forming the base of the island. The foundation is characterized by round mass of solidified lava, indi-cating an under-water eruption. With time, the volcano eroded, leaving large massifs.
2) Older Volcanic Series (6.2 – 5 million years ago). The island is about 40 km of diameter and 900 m high. Then cracks start to appear, eroding the slope of the shield. A caldera of 24 km diameter is left on the surface, surrounded by valleys.
3) Intermediate series (3.5 – 1.9 million years ago). The erosion continued, until new volcano eruption filled the bottom of caldera with volcanic lava flows. They were more intense and occurred particularly in the southwestern part of Mauritius.
4) Younger volcanic series (700 – 25 thousand years ago). A secondary rift was reactivated, causing new eruptions. 26 craters were in activities.

3. Geology, geomorphology and hydrography of Mauritius

The geomorphology of Mauritius [1] is distinguished by a central plateau, surrounded by a ring of discontinuous mountain. A steep transition is observed between the two reliefs and as it approaches the sea level, they transition smoothly into coastal plains with low insignificant slopes.

Each series of eruptions is different from one another in dimensions and types of lava which explains the variation of reliefs and types of soils overlying the island. The lava from older eruptions went through an erosion process before the eruption of younger series. The lava from the older eruptions have been more intensively weathered, yielding more clay materials. Laterites are observed on the very humid high south-western region. The coastal plains on the south-eastern side have a drier climate and are less subjected to weathering. Rock outcrops are very common in these regions.

The hydrography of Mauritius is unevenly distributed and many regions do not have surface watercourses. Grand Bassin and Bassin Blanc lakes, located in the southern central part, are among the few ones existing on the island and remain the largest natural lakes on the island. Heavy rains, mostly during cyclonic periods, induce erosion in most places.

Fig. 1: Geomorphology of Mauritius [2]

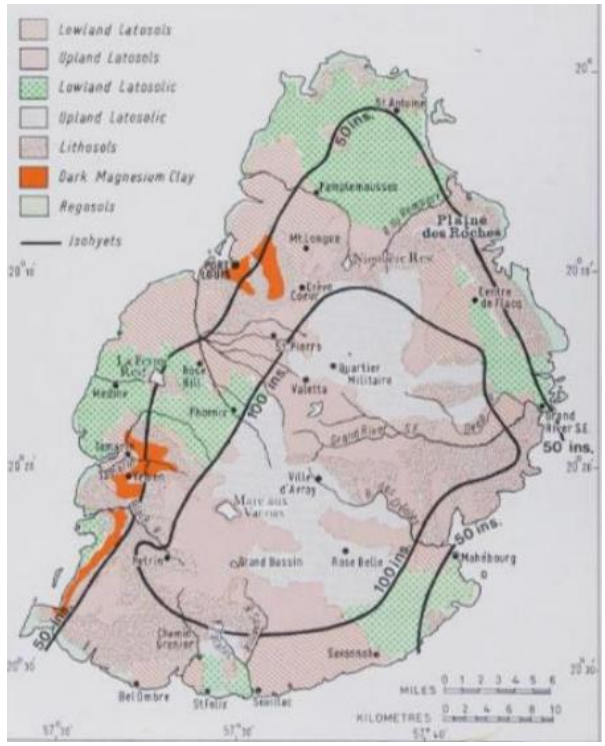

Fig. 2: Main types of soil in Mauritius [4]

4. Geodynamics in Mauritius

Geodynamics of the island of Mauritius is mainly characterised by the existing and potential landslide hazards, resulting in the movement of a mass of rock, debris or earth down a slope [3]. The causes of landslide differ. It can be natural event such as rainfall, volcanic activity or as a result of human activities that affect the slope stability of the soil mass, or a combination of any of these.

There are three main types of landslide, that can be encountered in Mauritius [5]:

- destruction of slopes or slope failure: "a mass detaching from a steep slope/cliff along a surface with little or no shear displacement. Compared to landslides, the slope failure moves quickly on a small-scale and the inclination angle is relatively high (over 20 degrees)"
- rock falls: "foliated rocks and gravel start to fall down a slope, due to enlarged cracks in the bedrock or outcropped rocks"
- debris flows: "soil and boulders are liquefied by surface water or groundwater and tend to flow downwards rapidly through a mountain torrent"

These failures have been classified based on the hazard degree (low to very high). Their zones of occurrences have been recorded and summarized in the map below, Fig 3.

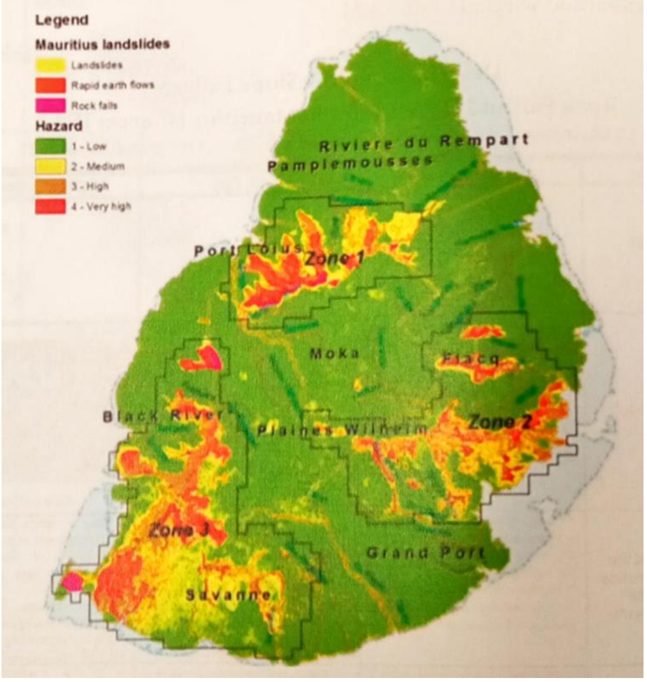

Fig. 3: Mauritius landslide zones [5]

The natural hazards, also called georisks, have been analyzed by Iegupov et al. [1] along with the sustainability resources. The reported information and published data have been used to carry out the investigation on Reunion Island, Mauritius, Rodrigues, Agalega and other coral islands/atolls. They are rated based on the gravity of the effects of their impact. The summary of the results is shown in the Table 1 below.

Table 1: Georisk assessment of the islands in southern Indian Ocean region

Georisks	**Reunion**	**Mauritius**	**Rodrigues**	**Agalega and other coral islands**
Seismic impacts*	High +++	Low +++	High +++	Depends on location +
Tsunami	Medium +++	Medium +++	High ++	High +
Volcanic eruptions**	High +++	Low +++	Medium +++	Unlikely
Landslides	Medium +++	Medium +++	Low +++	Unlikely
Rockfalls	High ++	High ++	Low ++	Unlikely
Mudflows	Medium ++	Medium ++	Low ++	Unlikely
Sea level rise	Possible +++	Possible +++	Possible ++	Possible +

Legend: Georisk level: high, medium, low, possible, unlikely

Sustainability resource: +++- high, ++- medium, +- low
*Earthquakes often cause landslides, rockfalls in the mountains, dilution of water-saturated soils and tsunamis
**Volcanic eruptions are often accompanied by volcanic eruptions and mild earthquakes

5. Stabilization of soils

Mauritius, of volcanic origin, shows multiple soil formations due to its geological history, including Residual Basalt, Latosols and Dark Magnesium Clays. Expansive soils, especially those located in regions like Baie du Cap, La Butte, and Tamarin pose considerable challenges for civil engineering projects. Expansive soils are characterized by their ability to expand upon moisture exposure and contract during arid conditions, resulting in significant damage to structures, roadways and other infrastructure. The erratic volume fluctuations of these soils render them challenging for building and land use planning [6,7].

To address these issues, soil stabilization techniques have been widely adopted in Mauritius, with lime stabilization being the most prevalent and effective method. This method involves combining lime with soil for improving its geotechnical characteristics. Lime interacts with clay minerals in expansive soils, reducing their flexibility while improving their strength. The chemical reaction results in the creation of cementitious chemicals with aggregate soil particles, hence improving its load-bearing capability and durability [6, 8]

Research on Dark Magnesium Clay in Mauritius shows the significant advantages of lime treatment. The California Bearing Ratio (CBR) of treated soil is usually 4–10 times greater than untreated soil only two hours after treatment. This considerably eases on-site transportation [6, 9].

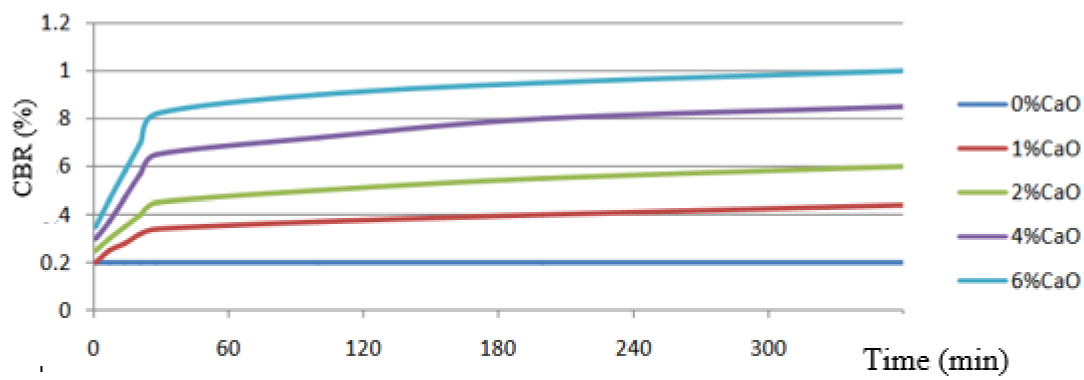

Fig. 4: CBR vs Time (min) [6]

Moreover, lime stabilization reduces the soil's flexibility index, facilitating transportation and improving compaction properties. Enhancement in compaction characteristics namely maximum dry density (MDD) and optimum moisture content (OMC), further improve the stability of the soil [6, 9].

In addition to lime stabilization, alternative soil stabilization techniques, including the utilization of industrial wastes (e.g., fly ash or stone dust), have been investigated worldwide. As at date, lime is the favoured choice in Mauritius because to its accessibility, economic viability, and proven efficacy in mitigating issues associated with expansive soils [10].

The stabilization of expansive soils in Mauritius via lime treatment is essential for reducing the threats linked to soil shrinkage and swelling. This approach enhances soil engineering performance and promotes sustainable infrastructure development in areas underlain by Dark Magnesium Clay [8, 11].

6. Conclusion

Over millions of years, tectonic and volcanic processes formed the Indian Ocean islands, particularly the Mascarene Islands. Volcanic phases show dynamic character and geomorphology of the Mascarene Islands. The main Island is overlain by deposits of Residual Basalt and Dark Magnesium Clay, as a result of weathering.

These soils, especially expansive Dark Magnesium Clay, pose geotechnical issues because to their swelling and shrinkage abilities which threatens infrastructure and requires stabilization. Lime stabilization, frequently used in Mauritius, improves the engineering qualities of these problematic soils at a relatively low cost, compared to other additives. The significant increase in soil strength, bearing capacity, and durability is strictly related to the genetic origin of the raw material and a sound understanding of the geological history of the region is important.

This paper highlights the impact of natural processes on the sustainable development by studying the Mascarene Islands' geological evolution and its expansive soils. Soil stabilisation techniques have been proposed to improve the geotechnical properties of the occurring soils.

References

[1] V. Y. Iegupov, R. Goodary, and I. Khrapatova, Engineering Geology. TOCHKA, 2021.

[2] 'Geomorphology of Mauritius'. [Online]. Available: https://www.maphill.com/mauritius/3d-maps/satellite-map/physical-outside/

[3] D. M. Cruden, 'A simple definition of a landslide', International Association of Engineering Geology, Bulletin 43, 1991.

[4] Ramdin, Mauritius a geographical survey, University Tutorial Press Ltd. 1969.

[5] Japan International Cooperation Agency, JICA and Ministry of Public Infrastructure and Land Transportation, MPI, 'Manual for Survey and Countermeasure of Slope Failure, Rock Fall and Debris Flow', 2017. [Online]. Available: https://openjicareport.jica.go.jp/pdf/11856424_02.pdf

[6] A. S. Negi, M. Faizan, and D. P. Siddharth, 'SOIL STABILIZATION USING LIME', vol. 2, no. 2, 2013.

[7] F. H. Chen, 'FOUNDATIONS ON EXPANSIVE SOILS'.

[8] R. Goodary, G. Lecomte-Nana, D. Teeluckdharry, V. Iegupov, and A. Morayndo, 'Influence of Red Lateritic Soils on the Geotechnical Properties of Expansive Dark Magnesium Clay', presented at the The 9th World Congress on Civil, Structural, and Environmental Engineering, Apr. 2024. doi: 10.11159/icgre24.107.

[9] K.S. Subba Rao, 'Swell-Shrink Behaviour of Expansive Soils - Geotechnical Challenges', Indian Geotechnical Journal, vol. 30 (1), 2000.

[10] Yo Nature, 'Formation of Mauritius Island'. [Online]. Available: https://www.yonature.com/formation-volcanic-island-mauritius/

[11] Landslide Management Unit: LMU, Ministry of Public, Infrastructure and Land Transport: MPI, and Republic of Mauritius, Technical Cooperation Project: Landslide Adviser for Mauritius. Japan International Cooperation Agency (JICA) Kokusai Kogyo Co., Ltd., 2018.