مجلة كلية الآداب بالوادي الجديد- مجلة علمية محكمة- إبريل ٢٠٢٤

A Geomatics approach to the Geomorphological analysis and landforms inventory of Jabal Al-Malasa area Medina - Saudi Arabia

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Abstract

This study presents a comprehensive geomorphological investigation of Jabal Al-Malasa area located in Medina, Saudi Arabia. And analyze the topographic features, landform characteristics, and underlying geological processes shaping the morphology of this area. Jabal Al-Malasa volcanic area covers an area of approximately 168.5 km² in Medina - Saudi Arabia. This region is recognized as the youngest volcanic field in the country and is situated within a potential National geopark area (Harrat Rahat). The fieldwork conducted in this area has revealed a diverse spectrum of volcanic landforms such as lava sheets, cones and Lava tubes, often associated with subsequent lava flow discharge that can develop various surfaces and appearances. Additionally, the area exhibits a variety of eruptive lava types, such as pahoehoe and A'ā lava flows. This study provides a volcanic geomorphological classification using remote sensing and GIS data, which can be utilized by a wide range of researchers, including educational institutions and geo-tourism entities. The findings of this fieldwork study contribute to the understanding of the region's volcanic landscape and offer valuable resources for both educational and geo-touristic purposes. The comprehensive data and classification system generated can facilitate effective access and relation with this unique natural museum situated in the Lava sheet environment.

Keywords: Geomorphology, Jabal Al-Malasa, Medina, Harrat Rahat, Lava Sheet, Volcanic Cone, Lava Tube, geopark

1. Introduction

The Lava Plateaus, locally known as Al-Harrats, is a unique geographical feature extending across the western region of Saudi Arabia. Harrat Rahat, the largest lava sheet, spans between the two holy cities of Medina in the north and Makkah in the south. Harrat Rahat is an extensive intra-plate volcanic field with a dimension of 75 × 310 km bracketed between 24°31′8″N, 39°42′15″E and 21°51′39″N, 40°22′49″E. It formed as part of the Cenozoic intraplate volcanism in the Arabian Peninsula that was dominated by alkali basalt and hawaiites (Camp and Roobol, 1989). This study focuses on the most recent volcanic eruption in Harrat Rahat, and indeed all of Saudi Arabia, which occurred in 654 AH - 1256 AD. This eruption lasted for several days, during which the lava advanced 23 kilometers towards the north and northeast. The lava flow ultimately halted just 8.2 kilometers short of the Prophet's Mosque in eastern Medina. As a result of this eruption, six new volcanic cones emerged, collectively referred to as the " Jabal Al-Malasa volcano".

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The study area is situated in the eastern region of Medina city, extending as a lava tongue for approximately 25 kilometers towards the north and northeast, covering an area of 168.5 square kilometers (1974year), Figure 1. The geographical coordinates of the study area are: Latitudes 24°53'27.13"N to 24°32'93.56"N and Longitudes 39°73'89.62"E to 39°78'46.66"E.

This study aims to apply the technology of Geographical Information Systems (GIS) and remote sensing to analyze satellite images and digital elevation models (DEM) covering the study area. The objective is to determine the locations of the geomorphological phenomena associated with the newest geological part of Harrat Rahat - Jabal Al-Malasa, which has scientific, cultural, and tourist importance, in addition to its potential for economic development. The study will also monitor the changes in Jabal Al-Malasa and its extension during the last fifty years, using remote sensing techniques. Furthermore, it will define the geological and geomorphological forms in the study area and shed light on one of the most important geological sites with high potential that could be nominated as a part of the first geopark in Saudi Arabia.

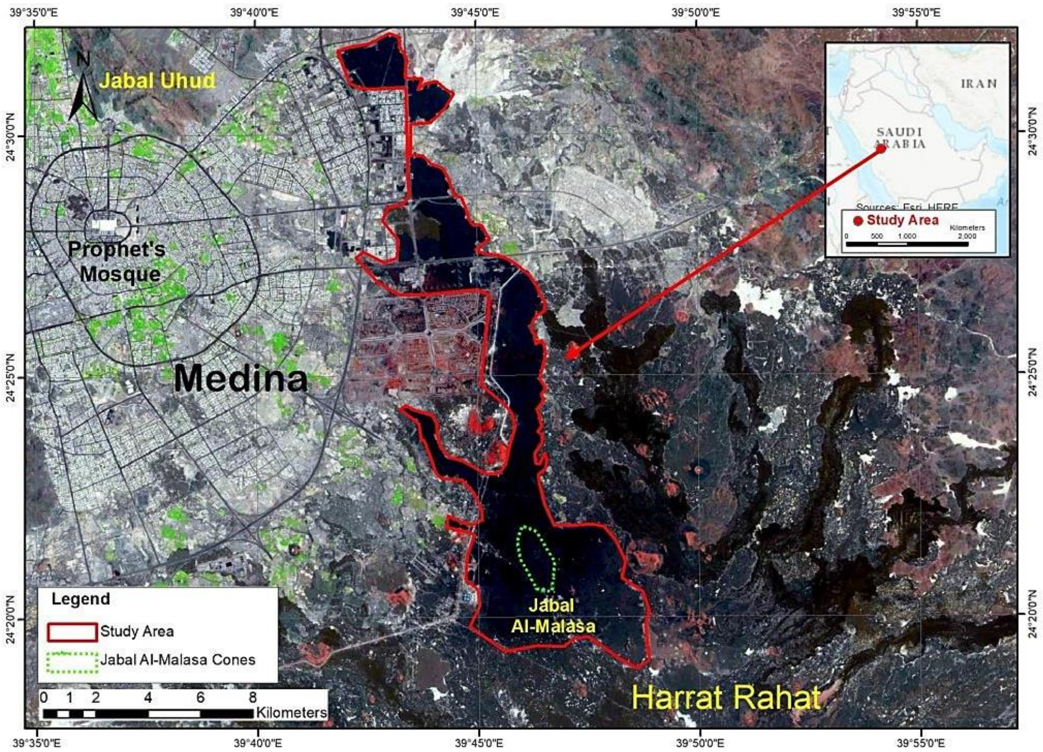


Figure 1: *location map ,Overview satellite image (SENTINEL; R=band 3, G=band 2, B=band 1) of the northern Harrat Rahat, showing the outline of the Jabal Al-Malasa area lava flow field (in 2024).*

2. Methodology:

The present research employs quantitative morphometric features to explore Jabal Al-Malasa using remote sensing and GIS methodologies, as shown in, *Table 1*

***Table 1**: Some characteristics of the used digital data.*

Data Type	Sensor	Spectral Resolution	Special	Year
LANDSAT-1	MSS	4-Bands(Visible & Infrared)	57 m	1974
LANDSAT-7	ETM+	9- bands(Visible & Infrared)	30 m	1999
LANDSAT-8	DOI (Multispectral)	9- bands(Visible & Infrared)	15 m	2024
SENTINEL	C-SAR sensor	3-Bands(Visible & Infrared)	20 m	2022
GeoEye-1	Pushbroom imager	4-Bands(Visible & Infrared)	41 cm	2017
DEM	Medina Digital Elevation Model -Space Dimension Technology		10 m	2012
Geological Map	Geological map of the Madinah quadrangle, sheet 24D. Kingdom of Saudi Arabia,		1:250000	1981
Topographic Map	Topographic Map of Al Madinah Al Munawwarah , ministry of petroleum and mineral reaources. Aerial Survey Department (A.S.D) Ar Riyad. Sheet3924-24/3924-21		1:50000	1981

ArcGIS 10.8 used in topographic and hydrologic analysis, it used also in creating this paper figures. While Erdas Imagine 2014 used in remote sensing analysis. As shown in, *Table 1* Landsat1 MSS (1974), Landsat7 ETM+ (1999), and Landsat 8 (2024), are compared to define the changes that have occurred in the study area over the past 50 years. High resolution GeoEye-1 image used to define and classified volcanic cones, Lineament structures are extracted from Sentinel-2 satellite imagery (2024), using PCI Geomatica program. Geological Map is utilized to assess the area's structure and lithology. Field Study is conducted using a GPS system to defined and measured micro feature in the study area, and confirm the findings.

3. Results & discussion

3-1 Geological Analysis

The geological history of the western region of the Kingdom of Saudi Arabia is characterized by a long-standing association between volcanism and the tectonic processes that led to the formation of the Red Sea rift. Harrat Rahat volcanic field is situated on the Precambrian basement rock, which comprises plutonic, volcanic and sedimentary rocks (Pellaton, 1981; Stoeser and Camp, 1985). The earliest eruptive product of Harrat Rahat dates back to 10 Ma ago, while the latest eruption is known to have occurred during the 13th century (Camp, V.E and Roobol, M.J ,1989)

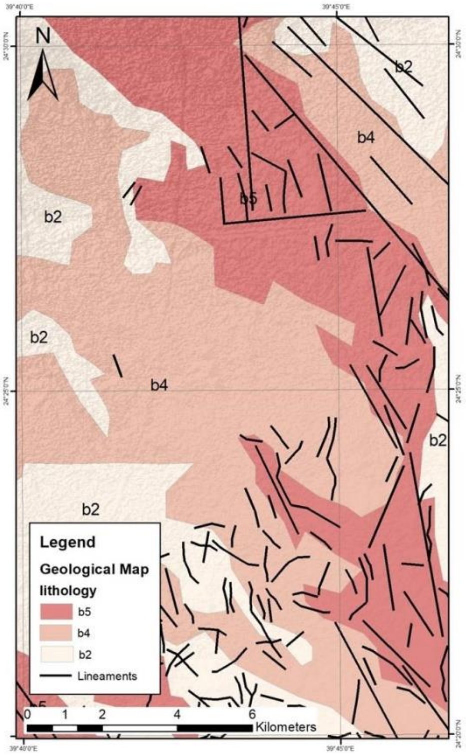


Figure 2: *Lithology map of Jabal Al-Malasa (modified after: geological map of the Madinah quadrangle, sheet 24D. Kingdom of Saudi Arabia, 1981) displays the surface covered by old and new Basalt in the area.*

The geological map depicts the existence of four distinct basalt volcanic formations *Figure2*, arranged in chronological order from the oldest (B2) to the most recent (B5), which corresponds to the contemporary basalt tongue that constitutes Jabal Al-Malasa.

Structurally the region is dominated by N–S and NW–SE normal fault systems related to a failed rift system along the Red Sea (Camp, V.E and Roobol, M.J ,1989). The structural lineaments of the study area were extracted from a Sentinel image acquired in 2024. The lineaments were initially constructed using the PCI Geomatica program and then manually edited to remove any false values. Analysis of the lineaments structure map and rose diagram *Figure3 (A)* revealed that the predominant trends were northwest (NW), north-northeast (NNE), and east-west (EW) which is relatively consistent with the direction of the Red Sea rift groove. The density of the lineaments increased towards the eastern and southern parts of the study area, as shown in *Figure3 (B).*

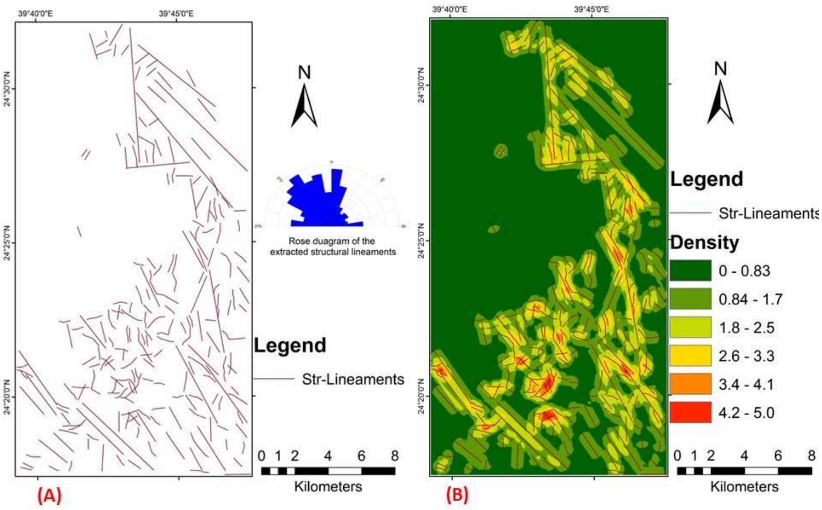


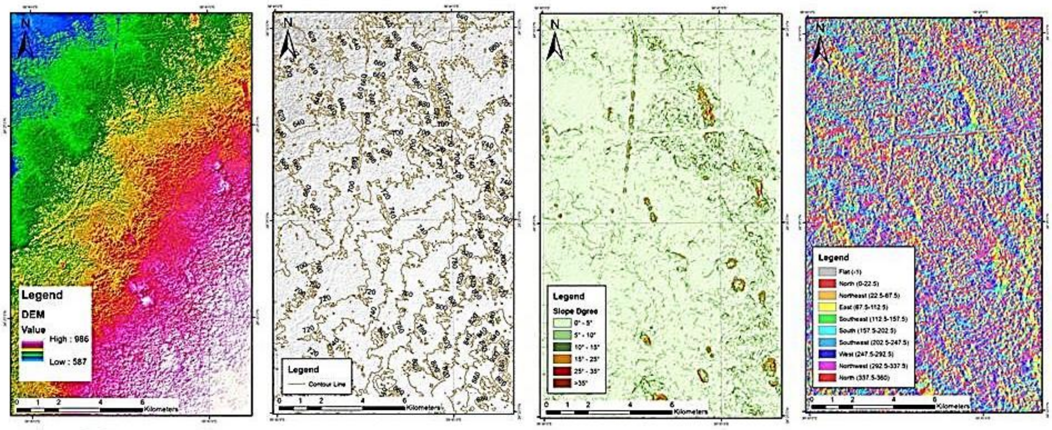
Figure 3: *Strucure mape of Jabal Al-Malasa: (A) Lineaments Map: The lineaments structure was automatically generated using the PCI Geomatica program, and subsequently edited to remove any false values. (B) Density map of the lineaments.*

Figure 4: *Stratigraphic sequence of Jabal Al-Malasa volcano (A photograph was taken by the researcher facing northeast)*

A mining site was one of the field study location observed the stratigraphic sequence *Figure 4*, at the mining site revealed the following geological history: The geological sector under examination exhibits a distinct layering of sedimentary and volcanic features. The lowermost layer consists of an ancient volcanic ash deposit, which suggests a period of significant volcanic activity and eruption in the region. This ash layer is subsequently overlaid by a layer of flood-related sediments, indicative of a subsequent period of water-based erosional processes. Finally, at the topmost portion of the geological profile, the presence of marginal volcanic lava is observed. This lava formation is attributed to the most recent eruption of the Jabal Al-Malasa volcano, which occurred in the year 1256 AD. The layering and sequence of these geological features provide a clear record of the region's volcanic history, transitioning from a period of heightened eruption activity to one marked by flood-driven sedimentation, then the most recent volcanic event associated with the Jabal Al-Malasa volcano.

3-2 Surface Analysis

SRTM-DEM used with surface analysis tool in ArcGis 10.8 to analysis the study area surface, and to create surface maps. *Figure 5*



(A) DEM (B) Contour Map (C) Slope Map -degree (C) Aspect Map

Figure5: *Surface analysis of Jabal Al-Malasa area , Map shows (A) Digital elevation model (B) Contour map (C) Slope map in degree (D) Aspect Map, creating using surface analysis tool in Arc GIS10.8 .*

The results of the surface analysis of the study area are presented in *Figure 5 (A)*. The SRTM-DEM data indicates that the elevation in the Jabal Al-Malasa region ranges from approximately 600 m to 1000 m above sea level, as illustrated in *Figure 5 (B)*. The data shows an increase in elevation from the north/west to the south/east within the volcanic field. The slope map in *Figure 5 (C)* reveals that the slope ranges between 0° and greater than 35°. The slope classes between 25° and 35°, or greater, represent the sides of volcanic cones and volcanic craters in the study area. The aspect map, presented in *Figure 5 (D),* refers to the direction of the terrain faces, which is influenced by the effect of the volcanic cones' circulation shape. In this map, 0° represents true north, and 90° indicates east.

3-3 Hydrological Analysis

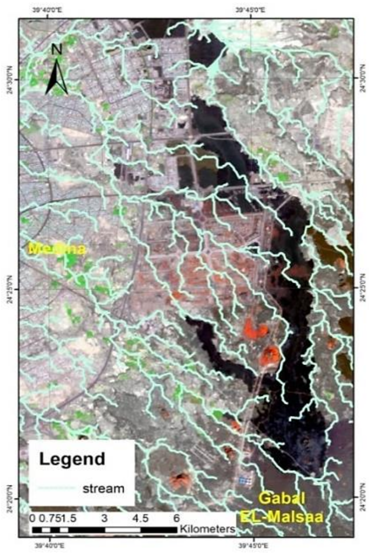


Figure 6: *Hydrological analysis of Jabal Al-Malasa*

In the study area, the streams and other recent fluvial features have been identified and extracted using satellite imagery and digital elevation models (SRTM-DEM) and Hydrological analysis tools in Arc GIS10.8. These features have been further verified using high-resolution GeoEye satellite imagery. The hydrological analysis of the study area reveals that it is intersected by numerous water tributaries. These tributaries originate from within the study area and predominantly flow in a southeast/northwest direction, eventually converging into the southern tributary is Wadi Qanat, which is one of the major valleys in the Medina region. *Figure 6*

The study area surrounding Jabal Al-Malasa is characterized by the presence of several seasonal and permanent streams. Although the typical radial pattern common to many volcanoes (Twidale, 2004), the streams in the area exhibit a dendritic drainage pattern. The pattern of tributaries within a drainage basin is largely dependent on the underlying geological features, including the type of rock and structures such as folds, fractures, and faults. The formation of drainage patterns is driven by the process of stream incision. As streams flow across the landscape, they erode the bedrock, creating valleys. The tributaries then join the main stream at the mouths of these valleys, shaping the overall drainage pattern.

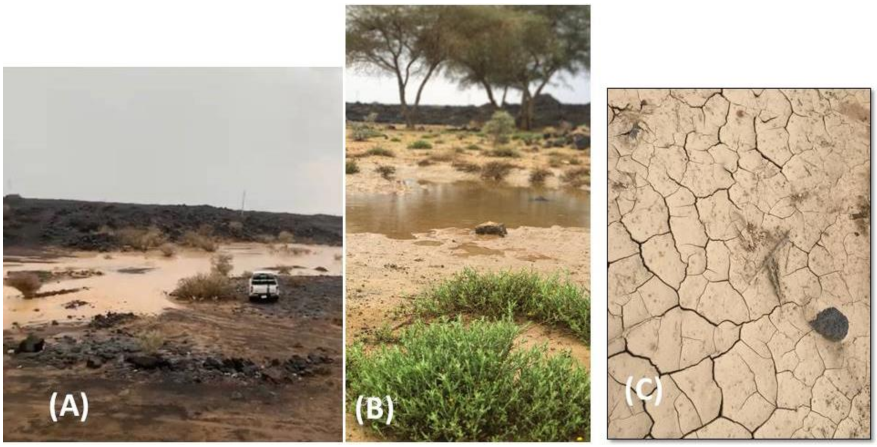


Figure 7: *Some Fluvial features in the Jabal Al-Malasa Area: (A) Streams flood runs of lava sheet after raining on April2022 (B) Sabkha below Cone2 (C) Clay Crack beneath volcanic cones*

The intense rainfall occasionally the water level within the drainage channels, leading to flooding in the fine tributaries that dissect the surface of the study area, as depicted in *Figure 7(A)*. This phenomenon is particularly prevalent during the summer months, coinciding with the presence of monsoon winds. Furthermore, the surface of the area is affected by rain in the winter season. The accumulated precipitation in the lower-lying parts of the forms several Sabkha, as shown in *Figure 7(B)*. These Sabkha quickly disappear as temperatures rise and the water evaporates. The clay surface of the study area is also susceptible to cracking, as illustrated in *Figure 6(C)*, due to the aforementioned processes of water accumulation and subsequent evaporation.

3-4 Volcanic landforms

Flow fields must be included in lava flow hazard assessment of the Harrat Rahat. This can expand the variety of eruption scenarios that can serve as a basis of a robust hazard estimate of the Harrat Rahat region. (Gábor Kereszturi, et.al.2016), Jabal Al-Malasa area contains a number of volcanic phenomena that represent the surface of the study area, which are:

3-4-1 Volcanic cones

Volcanic cones represent fundamental volcanic landforms formed through the expulsion of material from a volcanic vent, which accumulates around the vent, forming a cone shape with a central crater. The type of volcanic cone that develops is determined by the composition and size of the ejected fragments during the eruption. Monogenetic volcanic cones represent a common expression of continental volcanism (Németh, 2010) and occur in a variety of tectonic settings, most commonly extensional intracontinental rifting, and subduction settings (e.g., Hasenaka and Carmichael, 1985). The term "monogenetic eruption" has a wide range of definitions, but early definitions refer to small-volume eruptions ($\geq 1km^3$) which are produced by a single episode of volcanic activity without subsequent eruptions (Valentine, G. A., & Connor, C. B. 2015). In the study area, the observed volcanic cones are Cinder Cones (Scoria Cones), characterized by steep sides and formed by the accumulation of volcanic debris, such as ash and cinders, around a central vent. Cinder cones are typically smaller in size compared to other volcanic cones, such as stratovolcanoes and shield volcanoes, often displaying a symmetrical morphology.

Understanding the formation and evolution of basaltic cinder cones is an essential step toward a comprehensive understanding of volcanic processes. The use of Elevation Models (DEM) can provide majour geomorphological parameters, including the shape, slope, gradients, altitudes, and relief of volcanic landforms, which are valuable for understanding their morphological characteristics. The present Harrat Rahat surface exposed 644 scoria cones .They are as much as 100m high typically steep and open on one side where lava flows were extruded. They are commonly aligned north-to northwest trending fissures which coincide with the enteral vent axes of Harrat Rahat. (Camp, V.E and Roobol, M.J ,1989)

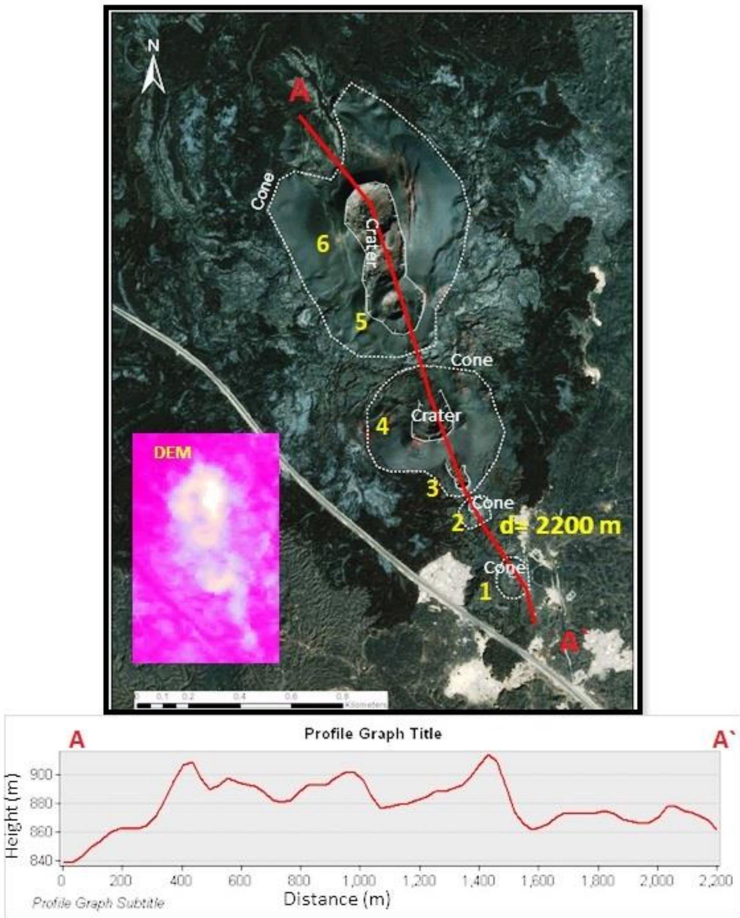


Figure8: *Geo-Eye satellite image with a resolution of 41 cm(R=band 4, G=band 1, B=band 2), view of the six cones and craters inferred to be the source of the Jabal Al-Malasa area*

The cinder cones have been categorized using different morphological classifications (Thuoret, 1999). Traditionally, these classifications (morphogenetic or morphological) have only considered. In this study there are two main morphological categories of cones, ring-shaped cones and horseshoe cones. The objective of this section is to categorize the cinder cones in Jabal Al-Malasa based on qualitative factors such as the shape and dimensions of cones and their craters. The data sources used for the spatial localization of the cinder cones and the morphometric analysis using a Geo-Eye satellite image with a resolution of 41 cm and DEM. *Figure8*

- **Classifications of cinder cones of Jabal Al-Malasa**

After analyzing the data presented in Table 2 and Figure 7, the cinder cones of Jabal Al-Malasa can be classified to two majour type a ring shape (Cones No. 1, 2, 5, 6) and a horseshoe shape(cones No. 3 and 4) , with a ratio of 2:1. *Figure 9*

- **The ring-or circular-type cinder cones**: The morphological and morphometric analysis of the ring-type cinder cones in the study area reveals that these shapes correspond to relatively simple cones with closed craters. The circular character and the closed shape of the crater can be attributed to several factors, the angle of the ballistic trajectories of pyroclastics ejected, scarce pyroclastic dispersal, geometry of the eruptive conduit, concentration of explosive eruptive activity at a point along the volcanic fracture, different dynamic behavior of volcanic vents, succession of explosive and effusive stages during an active period, and the topography of the volcanoes emplacement area (Dóniz-Páez, 2004; Dóniz-Páez et al., 2008, 2011, 2012; Kereszturi and Németh, 2012). These volcanoes take circular morphology, uniform slope flanks, and symmetrical cross-sections.

The ring-shaped morphology of these cones is a result of concentrated explosive activity at a specific section of the eruptive crack, leading to forming a crater (such as cone 2 with a symmetrical ring shape), or the coalescence of several vents with funnel morphology as seen in cone 6 with asymmetrical ring shapes. The main craters of these cinder cones generally have circular or slightly elliptical plans as cone 5.Volcanic cones can show eruptive fissures located in the external base of the volcanic edifice, which can emit abundant lava flows ,This is clearly appear in the northern part of volcanic cone 6. The presence of these eruptive fissures and the subsequent lava flow emissions are characteristic features of certain types of volcanic activity.

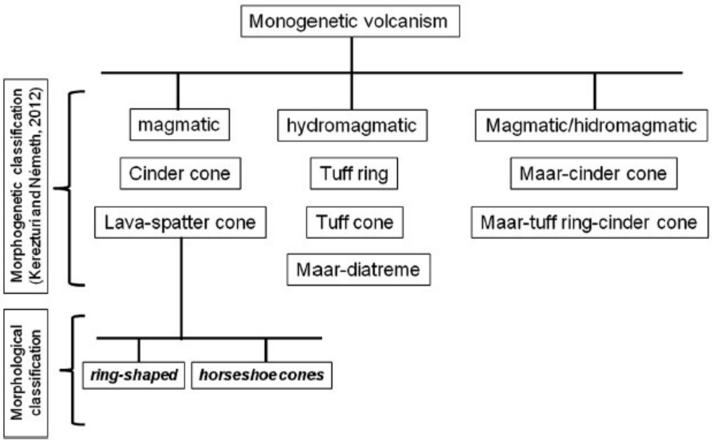


Figure 9: *Different classifications of cinder cones - Jabal Al-Malasa (*modified after Dóniz-Páez, J. 2015*).*

-The horseshoe-shaped cinder cones: Horseshoe-shaped volcanoes exhibit morphological features that are relatively simple, similar to ring-shaped cones. However, the morphology of this volcano type is more varied than that of ring-shaped cones. The distinctive characteristic of this volcano type is the main open crater and the absence of a portion of their flanks, which is associated with the topographical effect for cones 3 and 4. The lava flows have breached one of the volcano flanks.

These volcanoes have circular or elongated plans. The absence of a part of their flanks can be attributed either to a lack of construction or to their truncation by subsequent lava flow emissions. In both cases, the open character of the craters is related to several factors, such as wind blowing during the eruption, the inclination of the substratum, the alternation of explosive and effusive phases, and the geometry and orientation of feeder dyke (Dóniz-Páez et al., 2008; Bemis et al., 2011; Kereszturi and Németh, 2012)

Table2: *Classification table of cones according to their eruptive landform, height, width, elongation index*

Number	Eruptive Landform	cones				carter				vent
		Height(m)	length(m)	Width(m)	Elongation index	Height(m)	length(m)	Width (m)	Elongation index	Height(m)
1	ring-shaped	880.00	163.20	139.50	1.17	880.00	34.50	43.80	0.79	878.00
2	ring-shaped	900.00	114.00	132.30	0.86	900.00	40.90	45.20	0.90	875.00
3	horseshoe-shaped	903.00	181.00	293.60	0.62	903.00	133.90	83.10	1.61	885.00
4	horseshoe-shaped	902.00	398.30	535.50	0.74	902.00	198.60	177.10	1.12	900.00
5	ring-shaped	900.00	304.10	538.90	0.56	900.00	167.20	212.40	0.79	895.00
6	ring-shaped	920.00	727.10	733.90	0.99	920.00	391.20	196.50	1.99	914.00
	AVERAGE	900.83	314.62	395.62	0.82	900.83	161.05	126.35	1.20	891.17

Source: calculated by the researcher using Geo-Eye satellite image with a resolution of 41 cm and ArcGis10.8

Moreover, the heights of the six cones are relatively similar; the volcanic cones in the study area exhibit a range of heights, from 880 meters for Cone No. 1 to 920 meters for Cone No. 6, with an average height of 900.83 meters, *Figure 10* **.**This trend suggests an increase in the height of the volcanic cones towards the northern part of the study area.

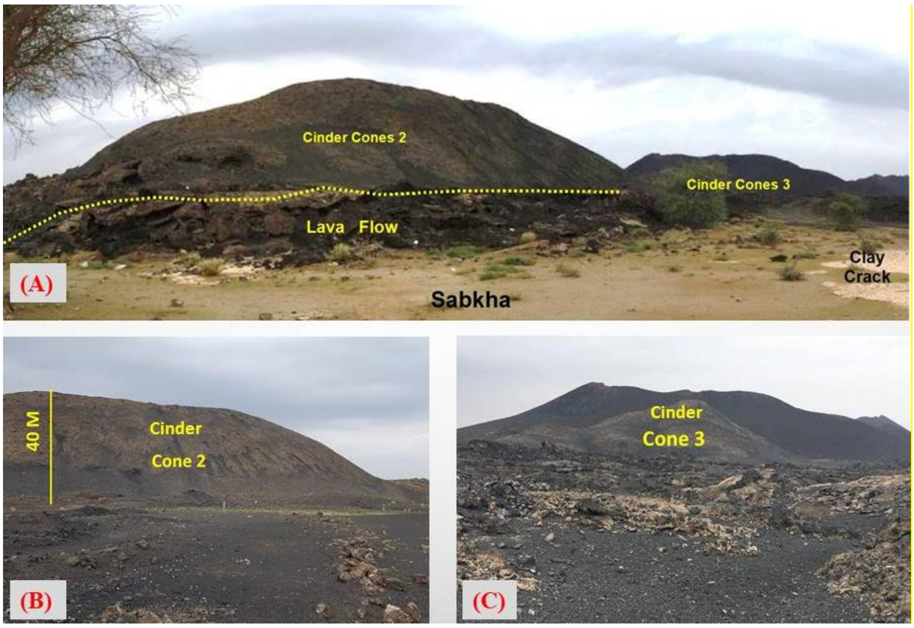


Figure 10: *Cinder Cones Shapes in of Jabal Al-Malasa (A photograph was taken by the researcher facing northwest), (A) panorama view of the geomorphological feature (B) Shows cone2 circular shape, (C) Shows cone3 shape.*

The elongation index, which denotes the ratio of length to width of the volcanic cones, has been found to exhibit a decreasing. This phenomenon can be attributed to the overlap and superimposition of certain cones. This process has consequently impacted the shape and longitudinal extension of the cones. The Elongation Index, which represents the ratio of the major to minor axes of the volcanic cones, has an average value of 0.82 across the cones. Nonetheless, Cone No. 1 shows a significantly higher Elongation Index of 1.17. This disparity can be attributed to the deformation of the shape of Cone No. 1, specifically the collapse of its western side. This structural change has resulted in an increase in the length of the cone, more than the width. In contrast, the remaining cones have a width that exceeds their length. The length of the craters varies, ranging from 391 meters (Cone 6) to 34.5 meters (Cone 1), with an average of 161.05 meters. The width of the craters also differs, ranging from 212.4 meters (Cone 5) to 43.80 meters for the smallest cone (Cone 1).The morphology of the craters in cones 3 and 4 is particularly noteworthy. These craters exhibit a distinct horseshoe shape, which has resulted in a more longitudinal extension compared to their width. Conversely, the craters in cone 6 have reached their maximum dimensions, as they are formed from the merger of two individual craters. Cone elongation represents in turn the distortion factors of the morphology of the volcano, and the former is obtained by dividing the cone major diameter by the cone minor diameter (Romero et al.,2000; Dóniz-Páez et al., 2008)

Lava Types

The largest historic eruption at 1256-AD that lasted ~52 days produced about minimum 0.29 km³ lava forming a maximum of ~23-km long and 8-m thick flow field (Murcia et al. 2014). This complex semi-confined to unconfined lava field is dominated by transitional flow textures typical for fast moving, open channel lava. Gradual transition from a shelly-, slabby-, and rubbly-pahoehoe, toward platy-, cauliflower-, and rubbly-A’a, reflects lava flow rheology changes (Murcia et al. 2014).

Lava Flows associated with the scoria cones vary from 4 to 10 m thick and are generally composed A'a with some Pahoehoe near their vent (Camp, V.E and Roobol, M.J, 1989).The term "A'a" refers to a Hawaiian designation for lava flows characterized by a rough, uneven surface. The uppermost layers of these flows consist of fragmented lava blocks. The sharp and rugged nature of a solidified A'a flow creates treacherous and arduous walking conditions. In contrast, the term "Pahoehoe" is a Hawaiian word used to describe lava flows with a smooth, ropey surface. Pahoehoe flow advance slowly, with small amounts of lava emerging from a cooler crust. These flows can exhibit a diverse array of shapes as they form and cool, *Figure 11*.

Figure 11: *The two types of Lava in the Jabal Al-Malasa area (A photograph was taken by the researcher facing west): (A)* A'a *Lava (B) Pahoehoe Lava*

The study conducted by (Gáb Kereszturi et al. 2016) revealed that the lava flow field comprises approximately 20.9% pahoehoe, 73.8% A'a, and 5.3% late-stage outbreaks. Field observations further suggest that the lava flows in the Harrat Rahat region are predominantly core-dominated and formed large lava flow fields through the amalgamation of numerous individual channels.

Lava Tubes

Lava tubes are natural conduits through which lava travels beneath the surface of a lava flow. Tubes form by the crusting over of lava channels and pahoehoe flows. During long-lived eruptions, lava flows tend to become channeled into a few main streams. Overflows of lava from these streams solidify quickly and plaster on to the channel walls, building natural levees or ramparts that allow the level of the lava to be raised. Lava tubes are very efficient transporters of lava from the vent to the flow front, and calculations show that lava flowing in a tube cools by only about 1 °C km− 1 (Walker R. J., 1991). Lava tube in Jabal Al-Malasa area extend as a large field of the Lava tube forming a complex network of small and narrow lava tubes between cone 2 and cone 3. These tubes have a small dimension less than 4 meters wide and 3 meters heights. *Figure 12*

Figure 12: *Lava tube in Jabal Al-Malasa area,Lava tubes forming a complex network of small and narrow lava tubes between cone 2 and cone 3*

<u>3-5 Change Detection</u>

In order to assess the changes that have occurred in the study area over the past five decades, monitoring was conducted for two distinct time periods, each spanning 25 years. The analysis utilized satellite imagery from Landsat 1 using the MSS sensor for the year 1974, Landsat 7 with the ETM+ sensor for the year 1999, and Landsat 8 equipped with the DOI sensor for the year 2024. The spectral signature of the lava within the study area was extracted from each satellite image and differentiated from other terrestrial phenomena using Erdas Imagine 2014. Subsequently, the size, shape, length and area of the designated region were compared for each respective year to determine the extent of change that has taken place. The analysis of satellite imagery, as illustrated in *Figure 13* and detailed in *Table 3*, reveals the following findings:

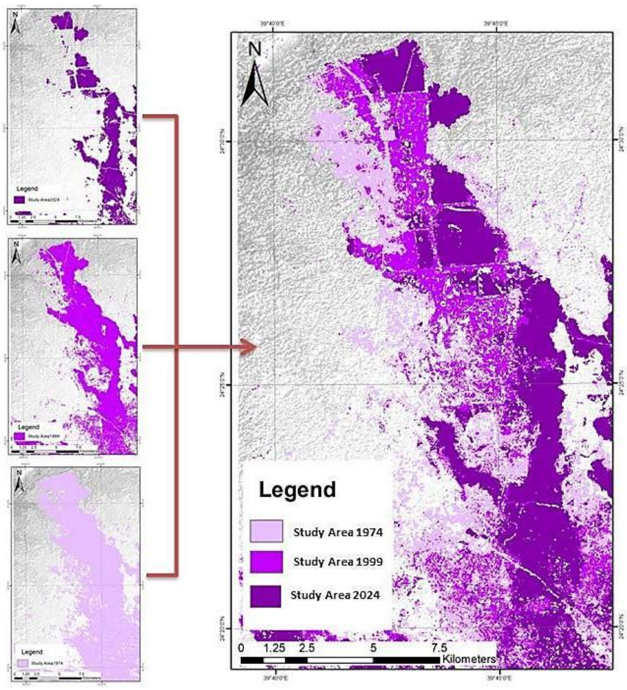
In the year 1974, the area of the lava tongue was approximately 168.5 km². Over the subsequent 25-year period, this area decreased to 117 km² by 1999, representing a percent change of -30.56%. The width percent change was calculated to be -24.18, This reduction was primarily attributed to urban expansion to the east towards the study area .While the length percent change was found to be -6.91.

By the year 2024, the lava tongue had further decreased to around 65 km². The Area percent change during this period increased to -44.47%, with the width percent change reaching its maximum at -55.07% due to ongoing urban expansion towards the eastern part of Medina City, including the development of new urban planned neighbourhoods such as King Fahed, Plateau, and Jasmine neighbourhoods. This period was characterized by extensive construction and urban development activities.

Table3: *Area's Change Detections between (1974 -2024)*

Year	Area (Km²)	Percent Change %	Length (Km)	Percent Change %	Width (Km)	Percent Change %
1974	168.5		24.6		9.1	
1999	117	-30.56	22.9	-6.91	6.9	-24.18
2024	64.975	-44.47	19.8	-13.54	3.1	-55.07

- Source: calculated by the satellite images analysis, using Erdas Imagine 2014.



Source: Spectral signature of Lava flow, using satellite images and Erdas Imagine 2014

Figure13: *Jabal Al-Malasa's Change Detections between (1974 -2024)*

Notwithstanding the obstacles presented by the Harrat areas for urban development, whether for residential or commercial purposes, the city has shown signs of expansion in an eastern direction. This course of growth appears to be the most viable option due to the challenging terrain surrounding the city, making it unfeasible to pave and develop areas in the north, south, and west directions. The presence of formidable mountains such as Jaba Ohud, Jabal Thawr in the northern part of Medina, Jabal Ayr ,the hills area , and the cones of Harrat Rahat in the south, as well as Umm Bajmah, Ghommah, and Ghrabah in the western part, have served as natural barriers impeding expansion in these areas. Therefore, the most sensible decision has been to concentrate urban planning efforts on the relatively smoother terrain to the east for the development of residential and service infrastructure.

4. Conclusions

The study area under consideration is the most recent geological site in Harrat Rahat, having been formed 768 years ago. Various geological and geomorphological processes have shaped the study area, resulting in its present unique appearance. Jabal Al-Malasa area boasts a diverse array of landscapes that document the active volcanic history of the western region of the Arabian shield, making the study area an ideal location to establish a geopark to conserve the geological and geomorphological heritage of Saudi Arabia. This young basaltic tongue presents valuable assets and warrants promotion. Concerted efforts by a dedicated team could facilitate the initiation of an engaging geotourism activity around these volcanic sites, thereby supporting the sustainable socio-economic development of the entire region. In conclusion, Jabal Al-Malasa shared many morphologies and morphometric characteristics with other cinder cones fields around the world.

The primary objective of this study was to understand the relationships between each of the classified groups and the structure of the basement rocks, which will enhance our understanding of the tectonic setting of the cinder cones fields. This young basaltic province presents several assets and needs to be promoted as other well-known foreign volcanic provinces. A collaborative effort between the research team and the Natural Park of Harrat Rahat could allow for the initiation of an interesting geotourism activity around these volcanic sites, thereby supporting the sustainable socio-economic development of the entire region.

Jabal Al-Malasa area has undergone significant changes over the past fifty years, with more than 60% of its area being utilized for urban development and human activities. The most significant changes have occurred on the western and northern sides, due to the expansion of the city and the increased density of the road network. This study recommends that the potential risks associated with urban expansion in areas with tectonic activity, even if limited, must be carefully considered. Comprehensive studies and ongoing tectonic monitoring are essential before undertaking such development projects.

Jabal Al-Malasa area requires further work to contribute to the scientific knowledge about the evolution of volcanic phenomena, and to fully exploit its scientific and geotouristic potential and assets, especially in the high-mountain part of the important and famous Holy city of Medina, which holds numerous tourist attractions catering to religious tourists throughout the year.

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