International Value of The Potential Al-Medina Volcanic Global Geopark in Saudi Arabia Revealed From Multi-Satellite Remote Sensing Data

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International Value of the potential Al-Medina volcanic Global Geopark in Saudi Arabia revealed from multi-satellite remote sensing data

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Abstract

The Global Geopark must be of international importance in terms of their scientific quality, rarity, aesthetic appeal and education value. The Saudi Arabia, as one of the important node countries along the Belt and Road, has developed at least nine Cenozoic basaltic volcanic lava fields in the western part, with a total area of 180,000 km^2. In this paper, the geological and geomorphic features of volcanic lava fields in western Saudi Arabia induced by the expansion of the Red Sea are interpreted using multi-source satellite images, such as Moderate-resolution imaging spectroradiometer (MODIS), Landsat-8 OLI (Operational Land Imager) and Gaofen-2 data. Our results show that the Al-Medina volcanic field (AMVF) has great advantages to become the potential volcanic Global Geopark in Saudi Arabia. This study indicates that : 1) AMVF has special international geo-scientific significance and rare natural attribute in geodynamic mechanism and lithologic characteristics; 2) AMVF has abundant volcanic landscapes, including completely preserved cones and craters and multi-phase lava flows from different eruption stages, which have great aesthetic appreciation and education values to attract the general public; 3) AMVF is close to the second holy city of Islam-Medina city, which has convenient transportation and is suitable to develop tourism to promote the local economy development; 4) AMVF had erupted repeatedly (the latest eruption was in 1256 AD), establishment of the Global Geopark can not only prevent potential geological hazard risks to Medina city from future volcanic eruptions, but also provide better protection and conservation to geoheritage sites being damaged by human activities.
Keywords: Geoheritage, Al-Medina volcanic field, Late Quaternary, Scientific value and aesthetic appeal, Multi-source remote sensing data.

1 Introduction

UNESCO (United Nations Educational, Scientific and Cultural Organization) Global Geoparks are single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development. Their bottom-up approach of combining conservation with sustainable development while involving local communities is becoming increasingly popular. At present, there are 161 UNESCO Global Geoparks in 44 countries [1]. The distribution of Global Geoparks around the world is presented in Fig.1. It shows that current Global Geoparks are mainly distributed in southwestern Europe and eastern Asia.

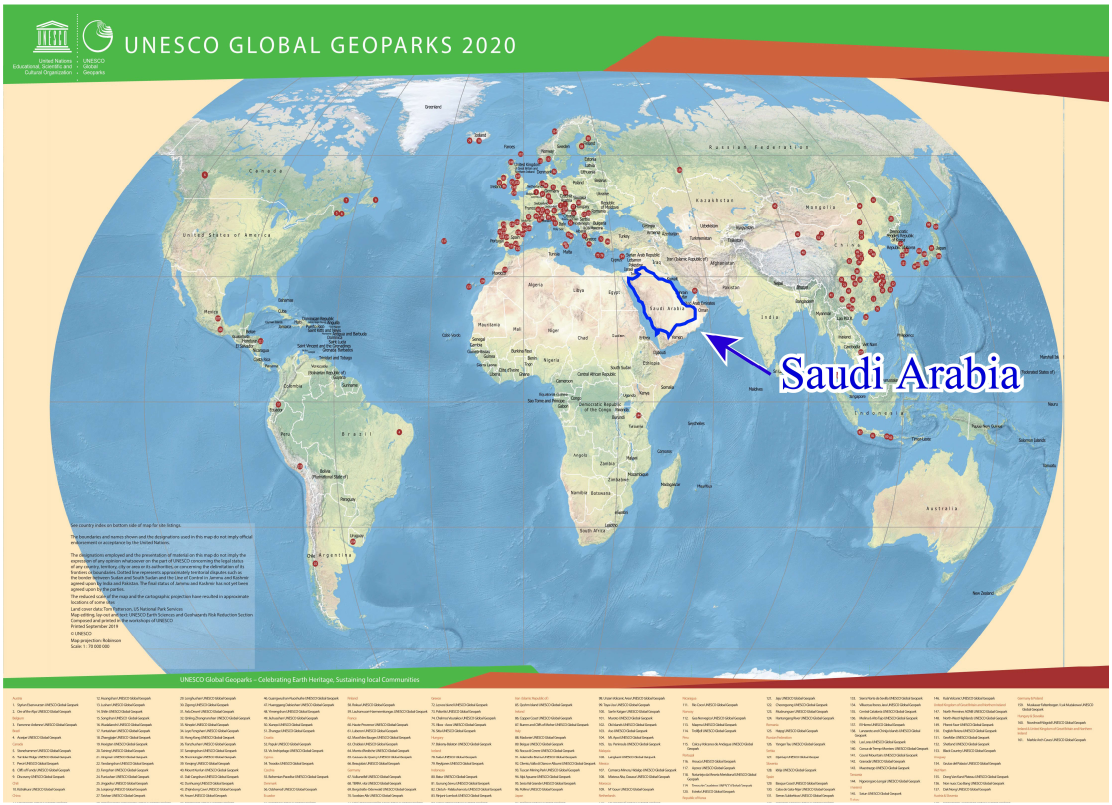

Figure 1 The distribution of UNESCO designated Global Geoparks around the world [2]

The Saudi Arabia, as one of the important node countries along the Belt and Road, has a land area of 2,250,000 km^2, ranking the 14th in the world. Induced by the expansion of the Red Sea, Saudi Arabia has developed at least nine Cenozoic basaltic volcanic lava fields in the western part, with a total area of 180,000 km^2. However, there is still no geoheritage site in Saudi Arabia has been inscribed on UNESCO Global Geoparks.

According to the criteria for UNESCO Global Geoparks [3], we interpreted the geological and geomorphic features of volcanic lava fields in western Saudi Arabia by using multi-source satellite images, including Landsat-8 OLI and Gaofen-2 data, in this study. We attempt to explore the international value of the Al-Medina volcanic field (AMVF) in Saudi Arabia according to the selection criteria of UNESCO Global Geoparks, and evaluate whether it has great advantages becoming the potential volcanic Global Geopark.

Following the introduction, detailed description of the study area Saudi Arabia is presented in Section 2. In Section 3, the methodology to interpret the geological and geomorphic features of Al-Medina volcanic lava field by using multi-source satellite images and the results are described. In Section 4, we briefly discussed the reasons for AMVF whether be able to become a potential volcanic Global Geopark. The conclusions are drawn in the last section.

2 Geological Background

Kingdom of Saudi Arabia, referred to as Saudi Arabia, is located in the Arabian Peninsula in the western Asia. It borders the Persian Gulf in the east and the Red Sea in the west, with a coastline of 2,437 km, as shown in Fig.2.

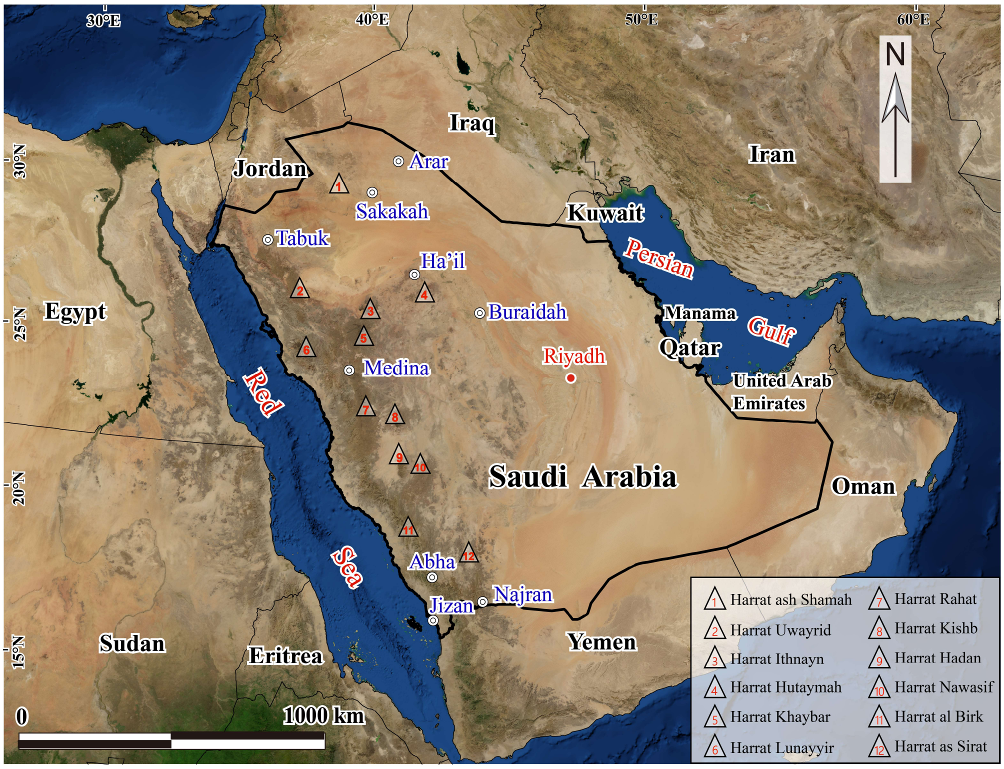

Figure 2 MODIS remote sensing image reveals the geographical location of Saudi Arabia and the distribution of Cenozoic volcanic fields in Saudi Arabia

Saudi Arabia occupies most of the Arabian Peninsula, topographically which is higher in west and lower in east. Along the Red Sea, there is a “backbone” of the Arabian Peninsula, named “Tuwaiq Mountain chain”, extending in a north-south direction in general. In east of the mountain, the terrain gradually declines until the eastern plain, where a large portion covered by sand dunes and rocky regolith [4].

The Red Sea Rift, a 2000 km-long NNW-SSE striking depression, forming a broad zone of active deformation between Africa and Arabia [5]. Rifting of the Rea Sea began about 30 Ma ago, separating the western edge of the Arabian Plate from Africa [6], as shown in Fig.3. Following that, the late Cenozoic geodynamic evolution of the Arabian Shield area was mainly controlled by (1) extensional processes as a consequence of the complex kinematic interactions that developed the Red Sea Basin [7-10], which are moving the Arabian Plate towards NE with a speed of 1.6-2 cm/yr.

[11-13]; (2) continental collision between Arabia and Eurasia to east since the middle Miocene [14-17].

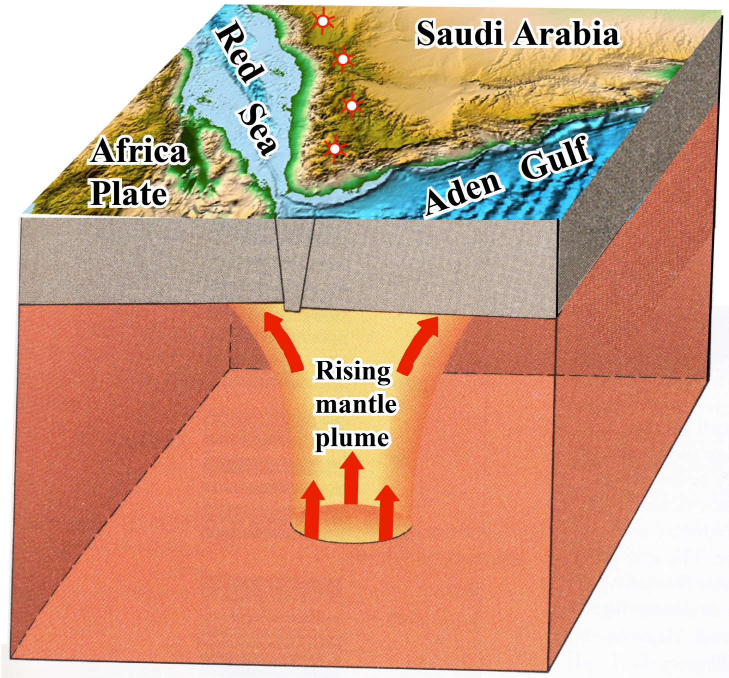

Figure 3 The three-dimensional (3D) geodynamic concept diagram showing that the active volcanoes in western Saudi Arabia are induced by the expansion of the Red Sea after the continental collision between Arabia and Eurasia (The figure is modified according to [18])

In response to this complex tectonics of the Arabian Plate, a series of large Cenozoic volcanic fields and volcanic rocks mainly developed along its western margin [19-26]. At least nine intracontinental Cenozoic basaltic lava fields parallel to the Red Sea Rift are developed in western Arabian Shield (Fig.2), with a total area of 180,000 km^2. These volcanoes and lava fields form a 600 km-long unique volcano chain from north to south in western Arabian Shield, named “Mecca-Medina-Nafud Volcano Line (MMN Line)”. Among the volcanoes, the Al-Medina volcanic field (AMVF), part of the Harrat Rahat in northwest of the Arabian Plate, is the worth notable active volcanic field characterized by the occurrence of two historical eruptions approximately in 641 and 1256 AD [5].

3 Interpretation of AMVF by remote sensing data

Based on the geological background, the geological and geomorphic features of the Al-Medina volcanic lava field in western Saudi Arabia are interpreted using Landsat-8 OLI (Operational Land Imager) and Gaofen-2 data, respectively.

3.1 Remote Sensing Data

3.1.1 Landsat-8 Satellite

Landsat satellites came from the National Aeronautics and Space Administration (NASA). Since July 23, 1972, this series had launched eight satellites. Landsat-8 satellite was successfully launched on February 11, 2013, with carrying two sensors: OLI and TIRS (Thermal Infrared Sensor). The bands of Landsat-8 are listed in Table 1.

Table 1 The bands setting of Landsat-8

No.	Band	Wave length(μm)	Spatial resolution (m)
1	Coastal	0.43-0.45	30
2	Blue	0.45-0.51	30
3	Green	0.53-0.59	30
4	Red	0.64-0.67	30
5	NIR(Near infrared)	0.85-0.88	30
6	SWIR1(Short wave infrared)	1.57-1.65	30
7	SWIR2	2.11-2.29	30
8	PAN	0.50-0.68	15
9	Cirrus	1.36-1.38	30
10	TIR1(Thermal infrared)	10.60-11.19	100

11	TIR2	11.50-12.51	100

The Landsat-8 image used in this study is the Level 1T data product with spatial resolution of 30 m, which have undergone systematic radiometric calibration and geometric correction by United States Geological Survey (USGS). The image used in this study was acquired on September 24, 2018.

3.1.2 Gaofen-2 (GF2) Satellite

Gaofen-2 satellite is the first civilian optical remote sensing satellite with spatial resolution up to 1 m developed by China. It was successfully launched on August 19, 2014 with two high-resolution sensor: 1 m panchromatic and 4 m multispectral cameras. The bands setting of GF-2 are listed in Table 2.

Table 2 The bands setting of Gaofen-2

No.	Band	Wave length(μm)	Spatial resolution (m)
1	Pan	0.45-0.90	1
2	Blue	0.45-0.52	4
3	Green	0.52-0.59	4
4	Red	0.63-0.69	4
5	NIR(Near infrared)	0.77-0.89	4

In this paper, we collected two Level 1-A GF-2 remote sensing images over AMVF area which were acquired on February 10, 2018.

3.2 Interpretation of the Landsat-8 data of AMVF

The spectral reflection characteristics of volcanic lavas with different lithological components or eruption periods are different in the remote sensing image. According to the previous study, the spectral reflectance of different weathering degree basalt volcanic lavas differs obviously in thermal infrared bands [27]. Therefore, Band 10 or Band 11 of Landsat-8 can be used to distinguish the weathering degree of volcanic lava. In addition, considering that the volcanic lava after weathering may contain hematite and aluminum elements, the near-infrared band (Band 5) and short-wave infrared band (Band 6 or Band 7) are selected to identify hematite and aluminum in the weathered lavas. Finally, Band 11, Band 5 and Band 7 are arranged for Red, Green and Blue channels of the Landsat-8 remote sensing image, respectively, which is shown in Fig.4.

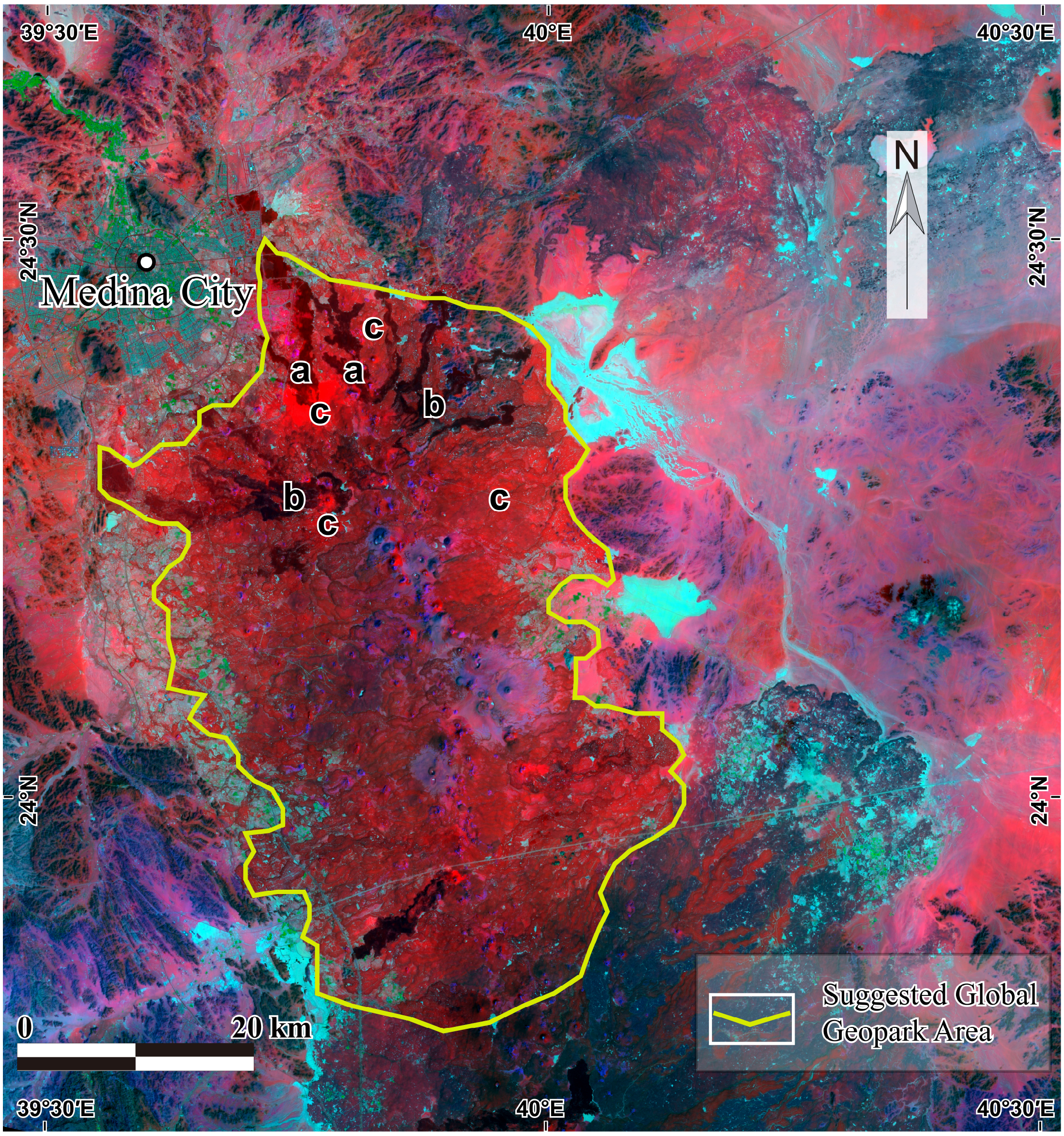

Figure 4 The pseudo-color composite of the Landsat-8 remote sensing image reveals the volcanic lavas from different eruption periods appearing different colors of the Medina volcanic field in Saudi Arabia (RGB as 11,5,7)

The pseudo-color synthesis of the Landsat-8 data shows that the volcanic lavas of Medina volcanic field can be divided into at least three periods: 1) the dark red part (marked by a in Fig.4); 2) the black part (b in Fig.4) and 3) the lighter red part (c in Fig.4).

3.3 Interpretation of the GF-2 data of AMVF

In order to judge the eruption periods of the Medina volcanic lavas more clearly, we obtained the Gaofen-2 data of the same area (Fig.5).

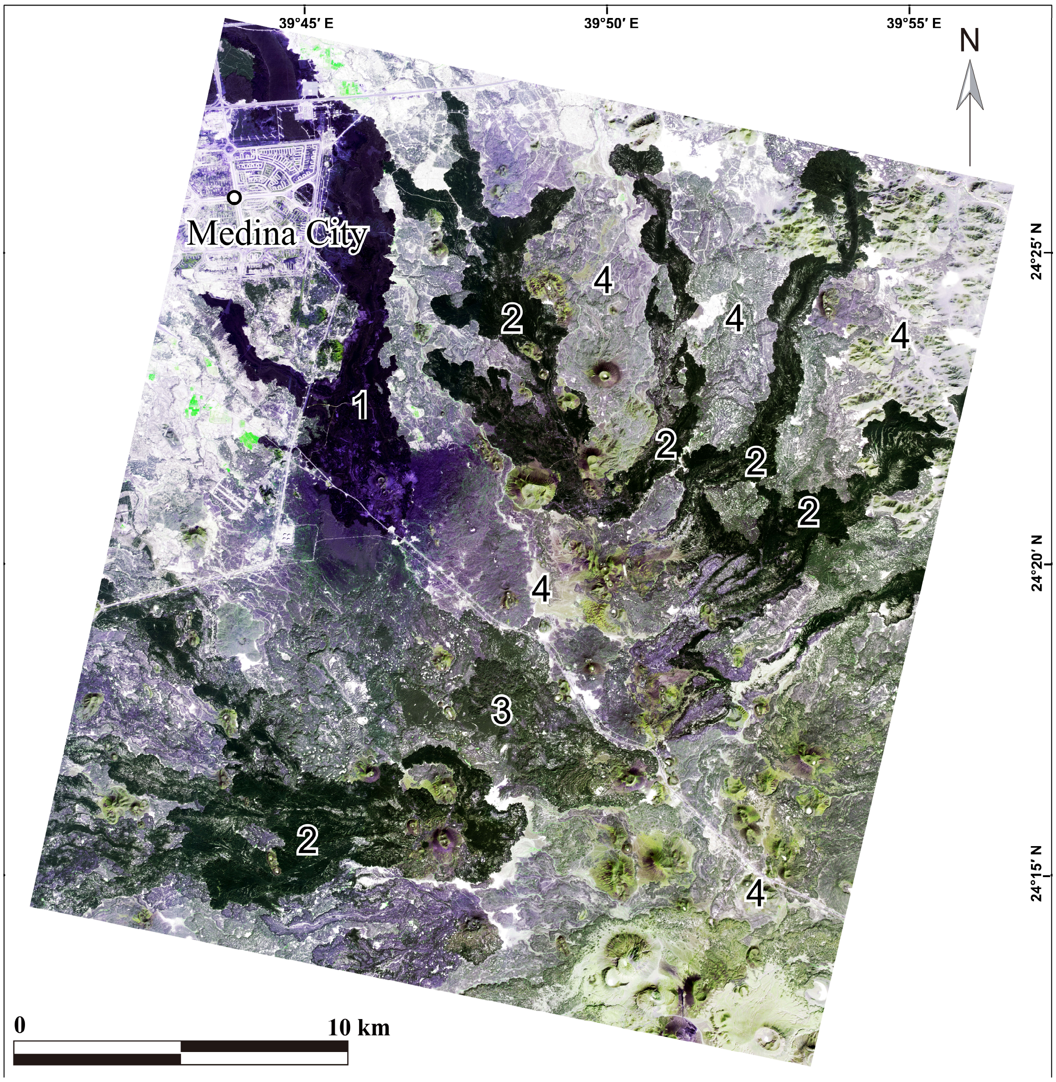

Figure 5 GF-2 satellite remote sensing image reveals the volcanic lavas from 4 different eruption periods of the Medina volcanic field in Saudi Arabia (RGB as 3,4,1)

The pseudo-color synthesis of the Gaofen-2 data shows that volcanic landscapes are widely distributed with different colors in Medina volcanic field, and it is speculated that at least four eruption periods can be identified: 1) the purple part (numbered 1 in Fig.5); 2) the dark green part (2 in Fig.5); 3) the lighter green part (3 in Fig.5) and 4) the off-white part (4 in Fig.5). There are about 50 craters of various shapes in the Medina volcanic field, and the most of them are cone-shaped, while some are shield-shaped craters.

Combining the results of previous research [5, 19, 28], we analyzed the GF-2 data of the Medina volcanic field and generated a 1:50,000 volcanic geological interpretation maps, as shown in Fig.6. The four eruption periods are interpreted as following.

1) the red pattern (numbered 1) in Fig.6, corresponding to the purple part (1 in Fig.5), belongs to the Qm7:~1500 BP-1256 AD, which is the latest volcanic lavas. According to the existing geological data, the last eruption of this volcano occurred in AD 1256. The lava flows generated by this eruption is very close to the Medina City；

2) the orange pattern (numbered 2) in Fig.6, corresponding to the dark green part (2 in Fig.5), belongs to the Qm6: ~4500-1500 BP, which represents the younger volcanic lavas;

3) the bright green pattern (numbered 3) in Fig.6, corresponding to the lighter green part (3 in Fig.5), belongs to the Qm5: ~0.3 Ma-4500 BP, which represents the older volcanic lavas;

4) the bright yellow pattern (numbered 4) in Fig.6, corresponding to the off-white part (4 in Fig.5), belongs to the Qm1-4: ~1.7 Ma-0.3 Ma, which represents the oldest volcanic lavas.

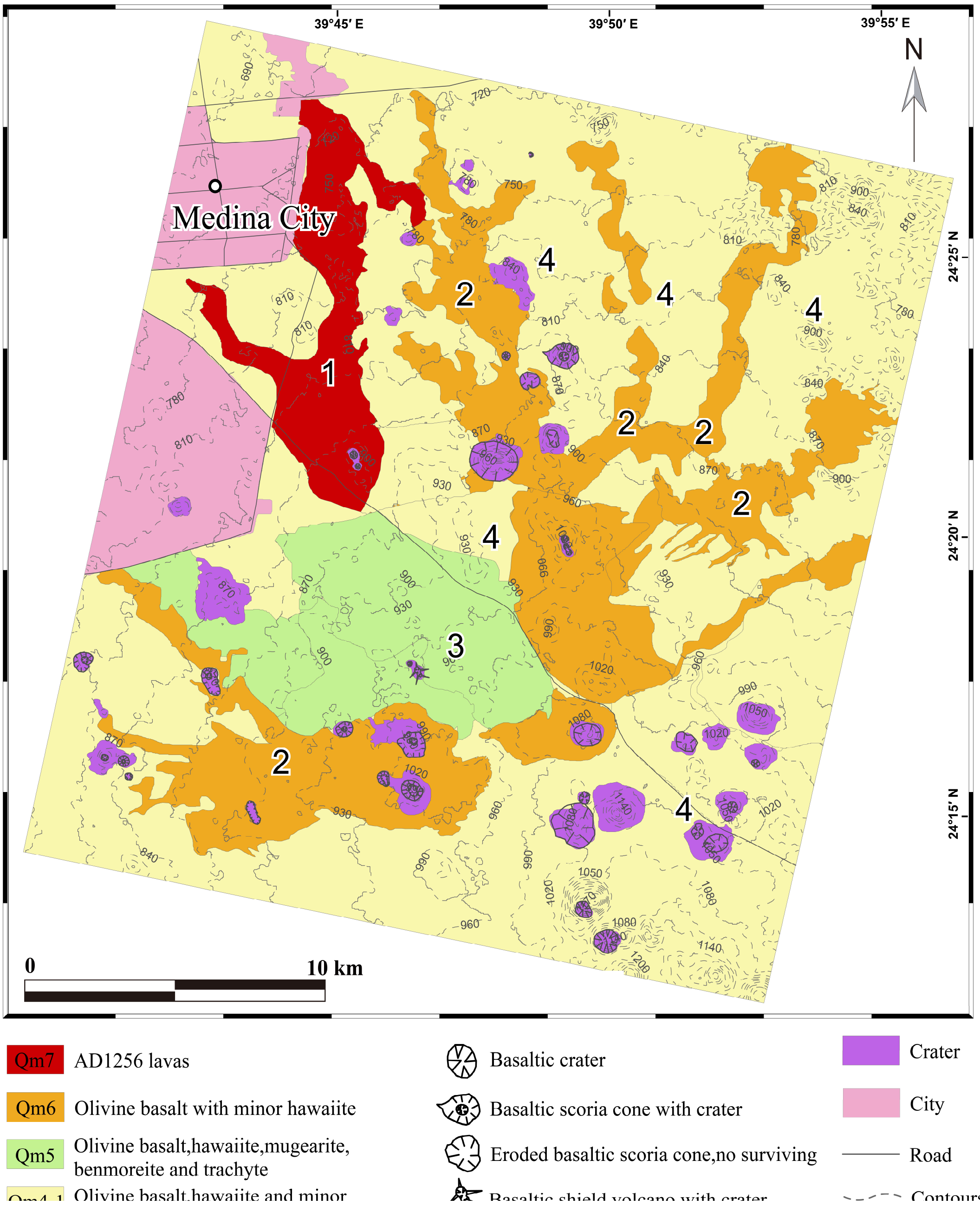

Figure 6 Geological interpretation map of Medina volcanic field from the Gaofen-2 image

The GaoFen-2 geological interpretation maps reveals that the Medina volcanic field had experienced multiple eruptions, and the exposed volcanic lavas appear different colors and forms after long time weathering. The lava flows produced from the latest eruption (Qm7) in the lava area is very close to the Medina city, indicating that future volcanic eruption may have potential disaster risks to the town. In addition, partial Medina city locates in this lava flows, also indicating that human activities may cause damage and destruction to this volcanic geological site. Therefore, the Medina volcanic field deserves more appropriate protection and management.

3.4 3D perspective view images of Medina volcanic field

Two typical regions in north and south of the Medina volcanic field were selected to generate three-dimensional perspective view images, as shown in Fig.7, 8 and 9. The 3D perspective view images were obtained by superimposing the Gaofen-2 remote sensing image on the digital elevation model (DEM) data with stretching the elevation value at the same time. The Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM) data with a spatial resolution of 30 m was used in this part.

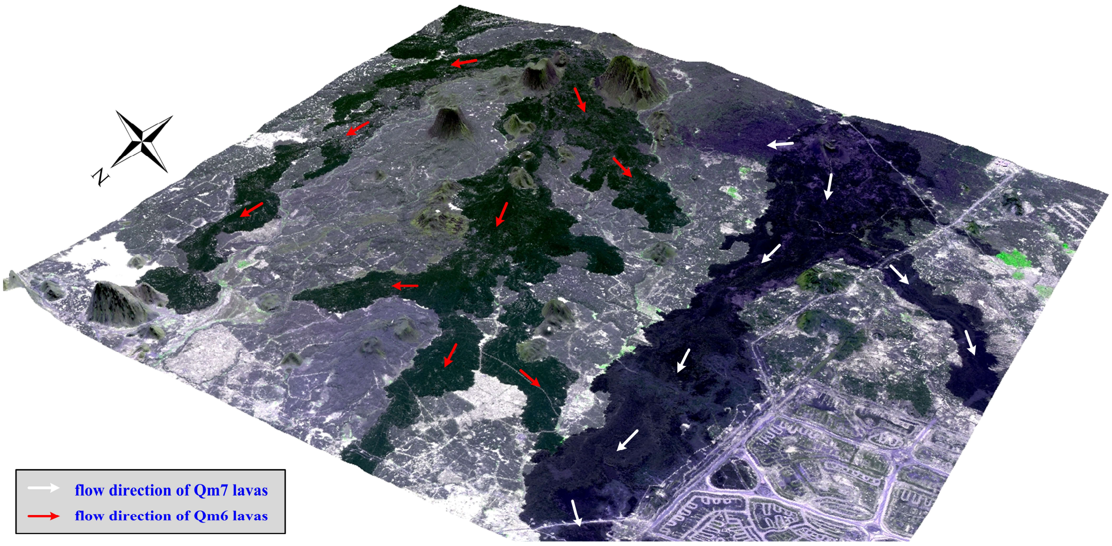

Figure 7 3D perspective view image reveals the different eruption periods and the flows direction in the north area of Medina volcanic field (view: WN-ES)

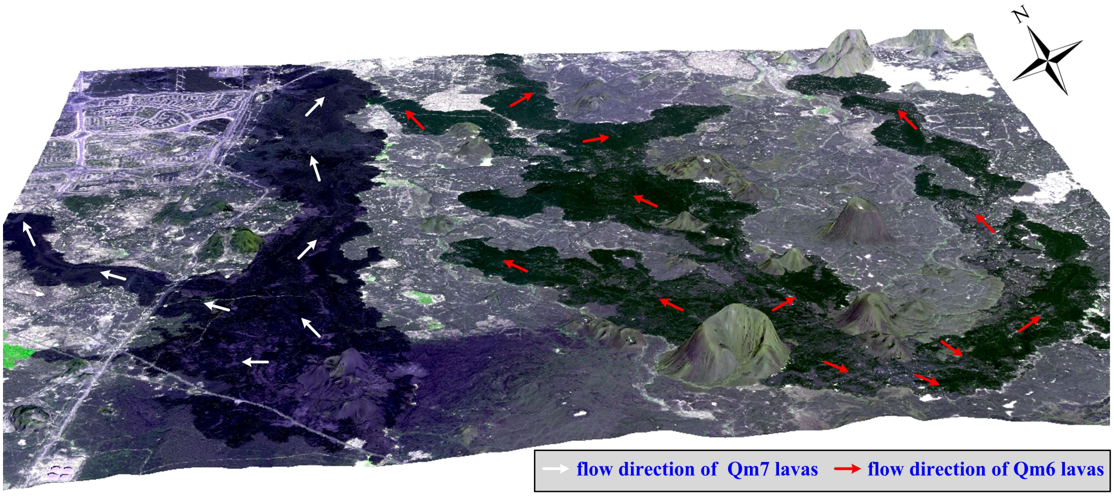

Figure 8 3D perspective view image reveals the different eruption periods and the flows direction in the north area of Medina volcanic field (view: N-S)

Two different volcanic lavas erupted in the north of the Medina volcanic field. The purple pattern is the latest volcano lavas from 1256 AD around the Medina city. Partial of the city was built in this period of lava flows, for example the roads are through these lava flows, indicating that human activities have caused damage and destruction to this volcanic geological site.

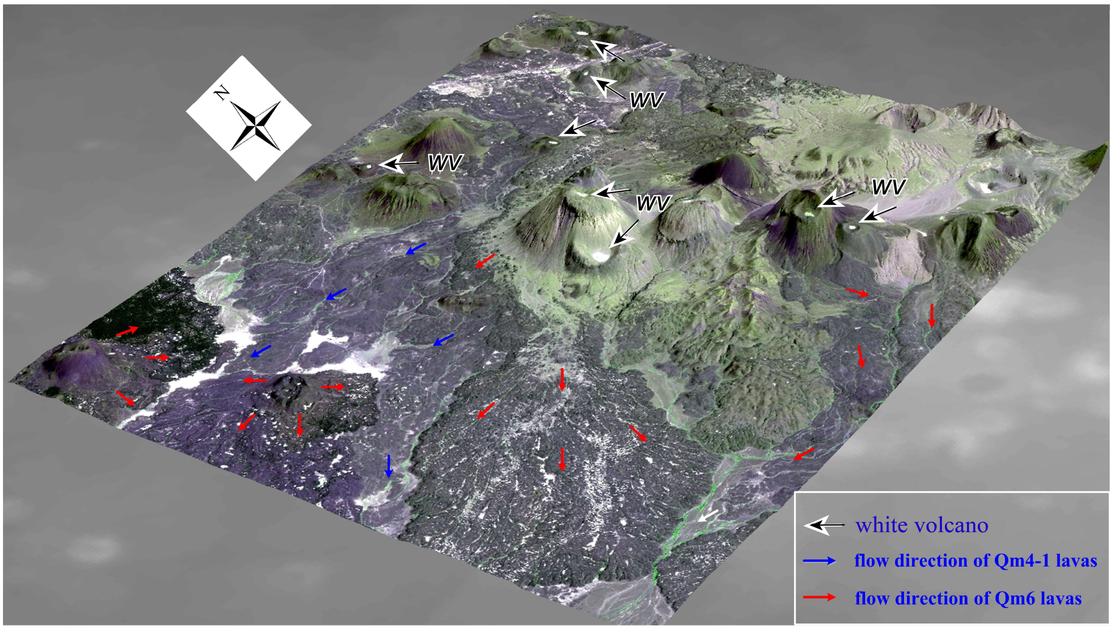

Figure 9 3D perspective view image reveals the different eruption periods and the flows direction in the south area of Medina volcanic field (view: WS-EN); WV means

white volcano

Multiple volcanic cones and multi-stage volcano lavas developed in the south of the Medina volcanic field. These volcano craters are well-preserved and have different shapes. Because of the bare vegetation, the coverage relationship between the volcano lavas produced in different eruption periods is very clear, which is benefit for tourism viewing. Rare examples of white volcanoes comprised mainly of the felsic rock comendite [29] can be seen clearly in some craters as shown in Fig.9, which is a unique volcanic type among the world.

4 Discussion

The interpretation results of multi-source satellite images indicate that the Medina volcanic field in western Saudi Arabia has the potential and advantage to become a volcanic Global Geopark for its uniqueness compared with other existing volcanic Global Geoparks:

1) Tectonically, the Medina volcanic field belongs to the hot rising mantle plume formed by the expansion of the Red Sea after the continental collision between Arabia and Eurasia to east since the middle Miocene (Fig.3). Its geodynamic mechanism is completely different with the back-arc volcanoes, such as the Japanese islands, and the intracontinental volcanoes, such as the Wudalianchi volcanoes in China [27]. The former are induced by the collision between oceanic and continental plates [18, 30], while the Wudalianchi volcanoes are formed by the deep subduction and dehydration of the west Pacific stagnant slab, possibly through hot and wet upwelling in the big mantle wedge under the NE China [27, 31-34].

2) Concerning the volcanic landscape, Medina volcanic field has developed abundant volcano lavas, including completely preserved scoria cones and craters, as well as multi-phase lava flows. Compared with the existing volcanic Global Geoparks, such as Wudalianchi Global Geopark [27] and Leiqiong Global Geopark [35], the AMVF not only has kinds of well-conserved volcanic geological sites, but also its

vegetation is sparse. Due to the sparse cover of vegetation, the lava flows from different eruption stages are well exposed on the surface appear different colors and forms after long time weathering, and the coverage relationship between the volcanic lavas produced in different eruption periods is very clear, which makes AMVF a natural geological museum showing abundant volcanic landscapes and aesthetic charm to the general public.

3) About the lithologic characteristics, there are rare and distinctive white volcanoes comprised mainly of the felsic rock comendite in Medina volcanic field, which is different from the existing volcanic Global Geoparks.

4) Concerning the volcanic hazard, Medina volcanic field is very close to the second holy city of Islam, which has convenient transportation and is suitable for general public to visit and receive science education. Moreover, the latest eruption of AMVF occurred in 1256 AD，only ca. 700 years ago. Therefore, future possible volcano eruption will have potential disaster risk to the city. Establishment of the Global Geopark can not only prevent potential geological hazard risks to Medina city from future volcanic eruptions, but also provide better protection and conservation to geo-heritage sites being damaged by human activities.

5 Conclusions

The interpretations and analyses of geologic and geomorphic features of volcanic lava fields based on multi-source remote sensing data can effectively identify the scientific, aesthetic and educational values of the potential volcanic Global Geopark. And help to recognize the suitable location and boundary of the potential Global Geopark. The results indicate that the Medina volcanic field in western Saudi Arabia has the potential and advantage to become a volcanic Global Geopark due to its unique international geo-scientific significance and rare natural value in geodynamic mechanism, volcanic landscape and lithologic characteristics. Furthermore, the AMVF has great aesthetic appreciation and education values to attract the general public and is suitable for developing tourism to promote the economic and social development. It is suggested to declare the Medina volcanic Global Geopark according to the area showed in the Fig.4.

List of abbreviations

UNESCO-United Nations Educational, Scientific and Cultural Organization

MODIS-Moderate-resolution imaging spectroradiometer

OLI-Operational Land Imager

AMVF-Al-Medina volcanic field

MMN Line-Mecca-Medina-Nafud Volcano Line

NASA- National Aeronautics and Space Administration

TIRS-Thermal Infrared Sensor

NIR-Near infrared

SWIR-Short wave infrared

TIR-Thermal infrared

DEM-Digital elevation model

ASTER GDEM-Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model

Availability of data and materials

The Landsat-8 remote sensing data used in this study are available in the https://www.usgs.gov/.

Competing interests

The authors declare no conflict of interest.

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Authors' contributions

Conceptualization, B.F. and H.F.; methodology, H.F. and B.F.; formal analysis, H.F., P.S. and Y.Z.; resources, B.F.; data curation, H.F. and P.S.; writing-original draft preparation, H.F.; writing-review and editing, H.F. and B.F.; figures, H.F. and P.S.; visualization, H.F.; supervision, B.F.; funding acquisition, B.F. All authors read and approved the final manuscript.

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Figures

Figure 1

The distribution of UNESCO designated Global Geoparks around the world [2] Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

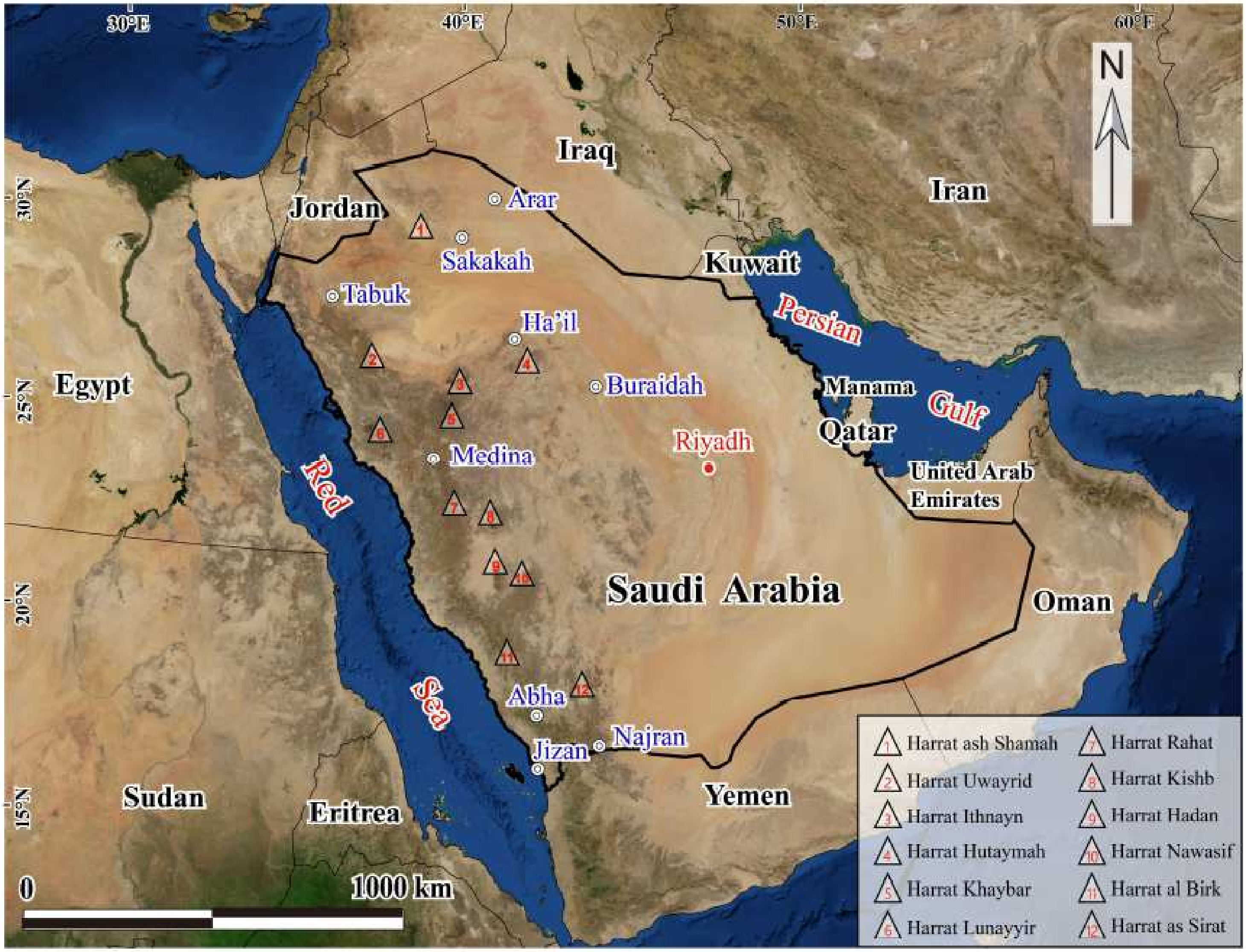

Figure 2

MODIS remote sensing image reveals the geographical location of Saudi Arabia and the distribution of Cenozoic volcanic fields in Saudi Arabia Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

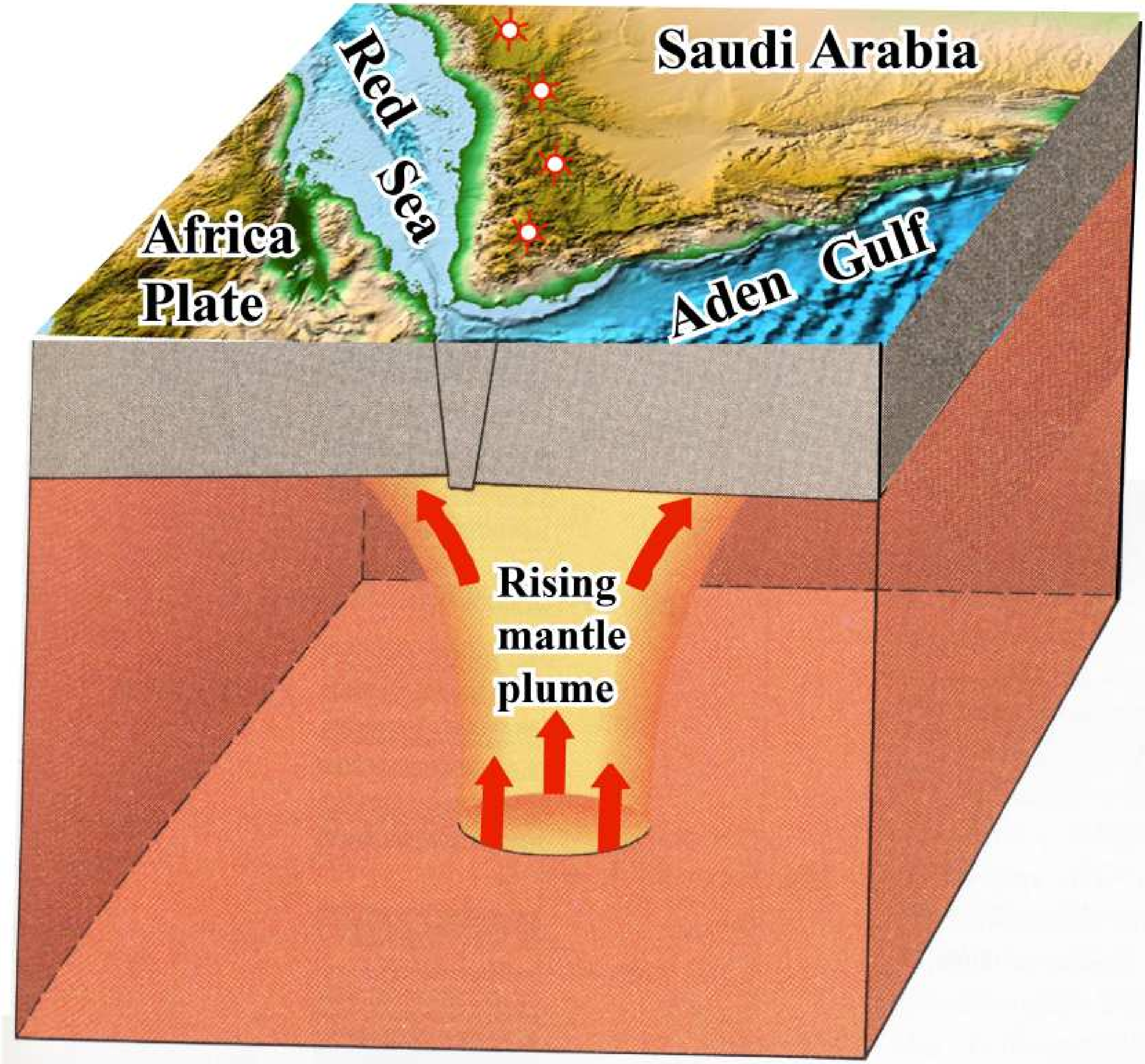

Figure 3

The three-dimensional (3D) geodynamic concept diagram showing that the active volcanoes in western Saudi Arabia are induced by the expansion of the Red Sea after the continental collision between Arabia and Eurasia (The figure is modified according to [18]) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

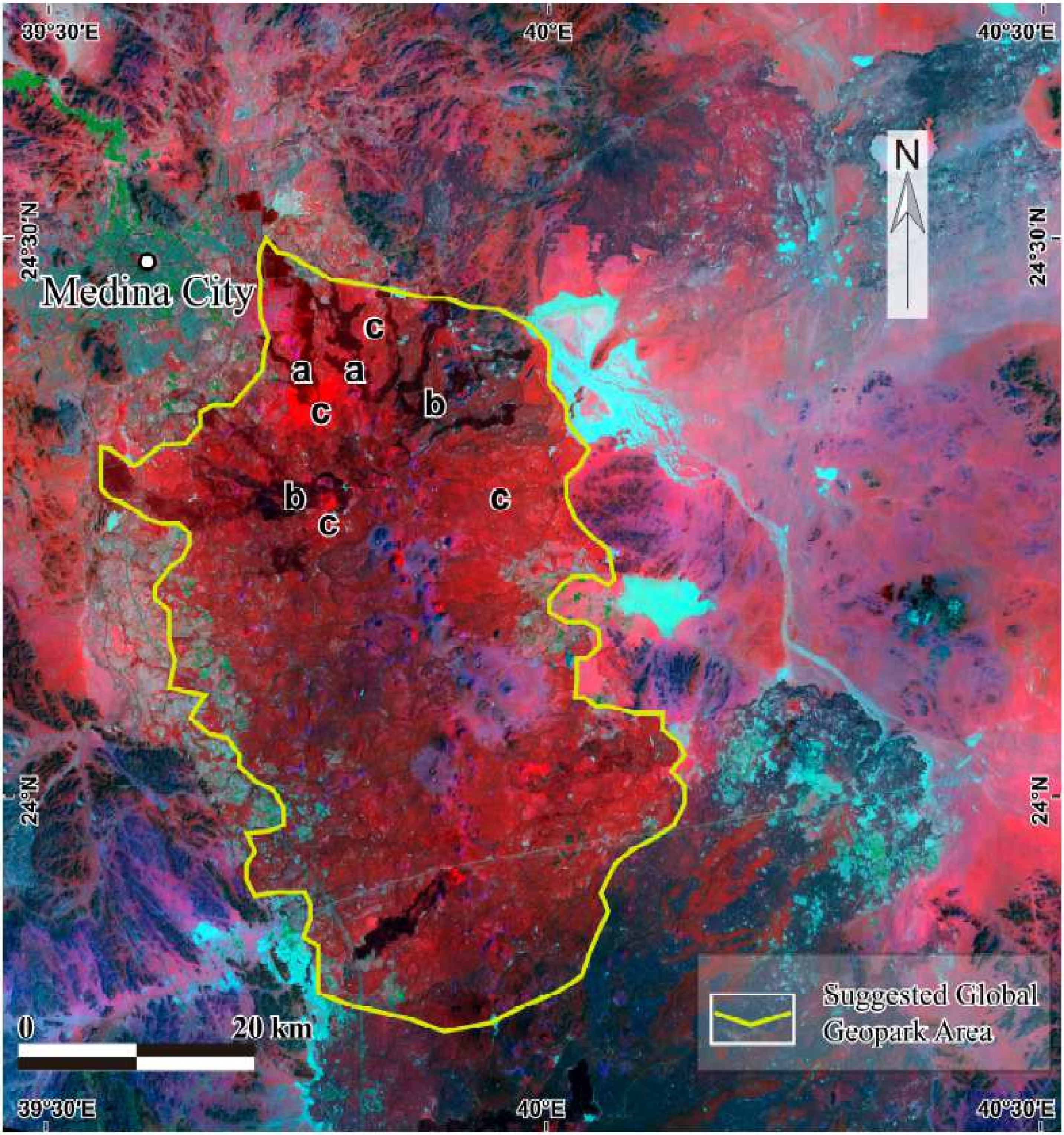

Figure 4

The pseudo-color composite of the Landsat-8 remote sensing image reveals the volcanic lavas from different eruption periods appearing different colors of the Medina volcanic field in Saudi Arabia (RGB as 11,5,7) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

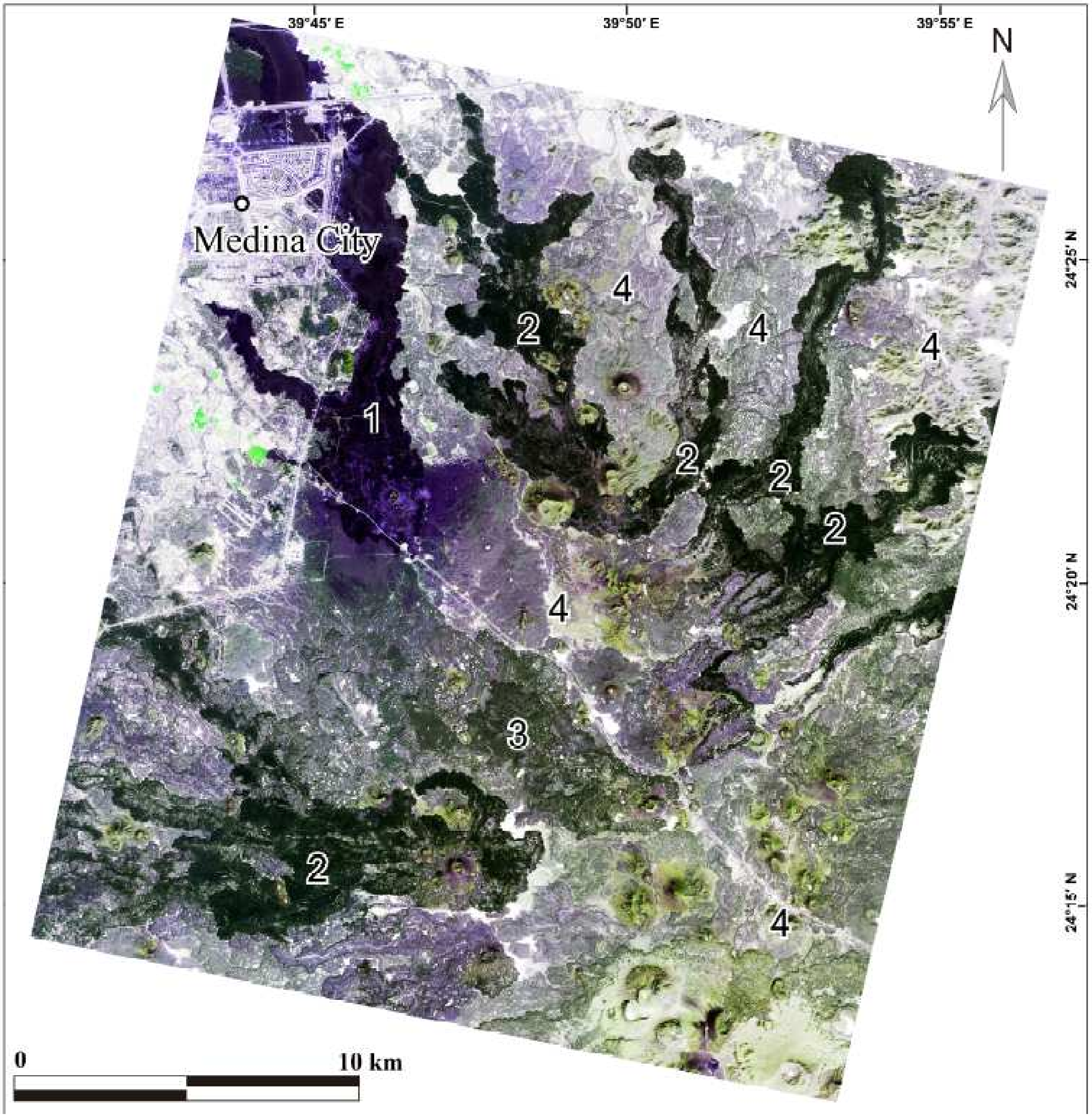

Figure 5

GF-2 satellite remote sensing image reveals the volcanic lavas from 4 different eruption periods of the Medina volcanic field in Saudi Arabia (RGB as 3,4,1) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

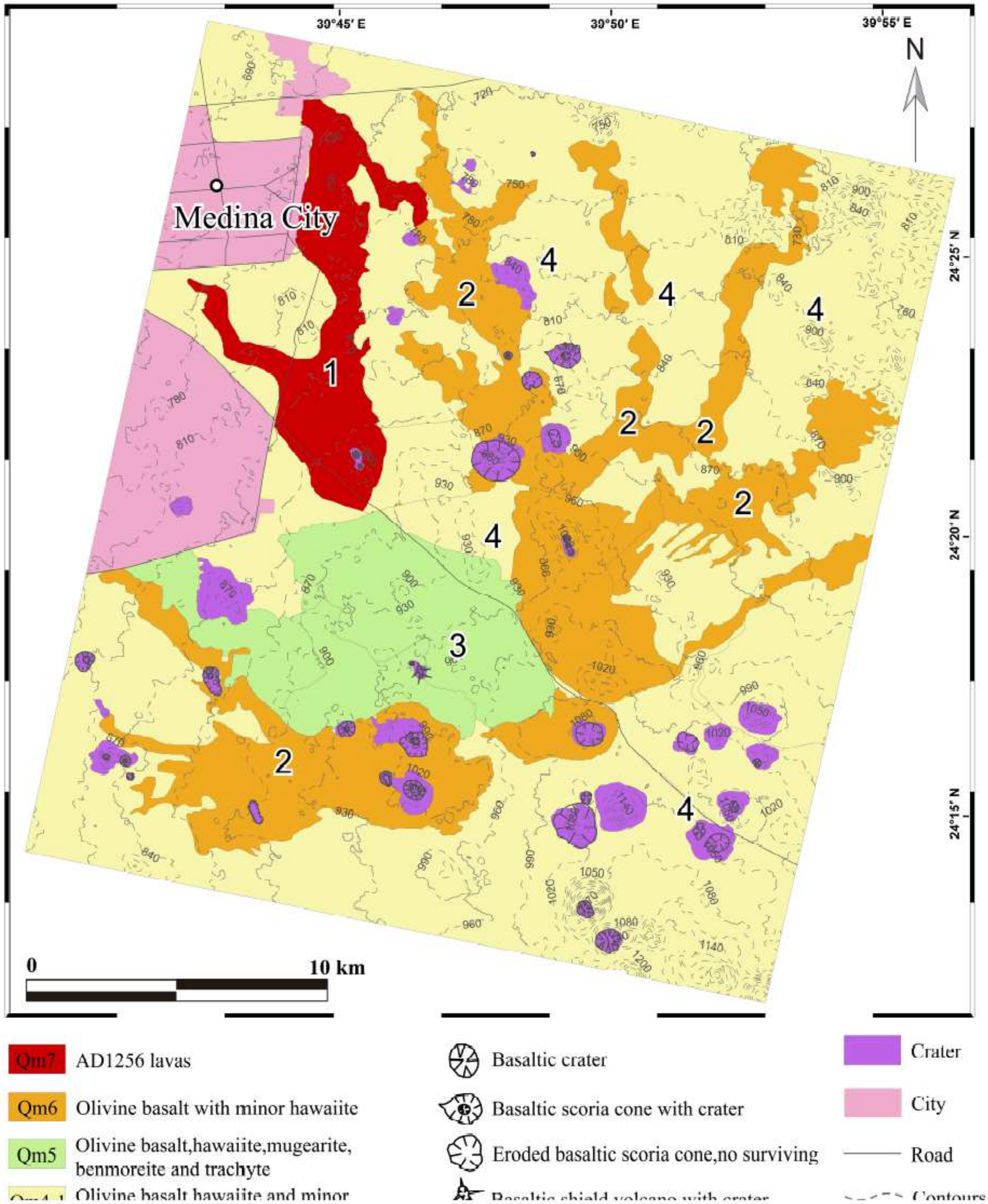

Figure 6

Geological interpretation map of Medina volcanic field from the Gaofen-2 image Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

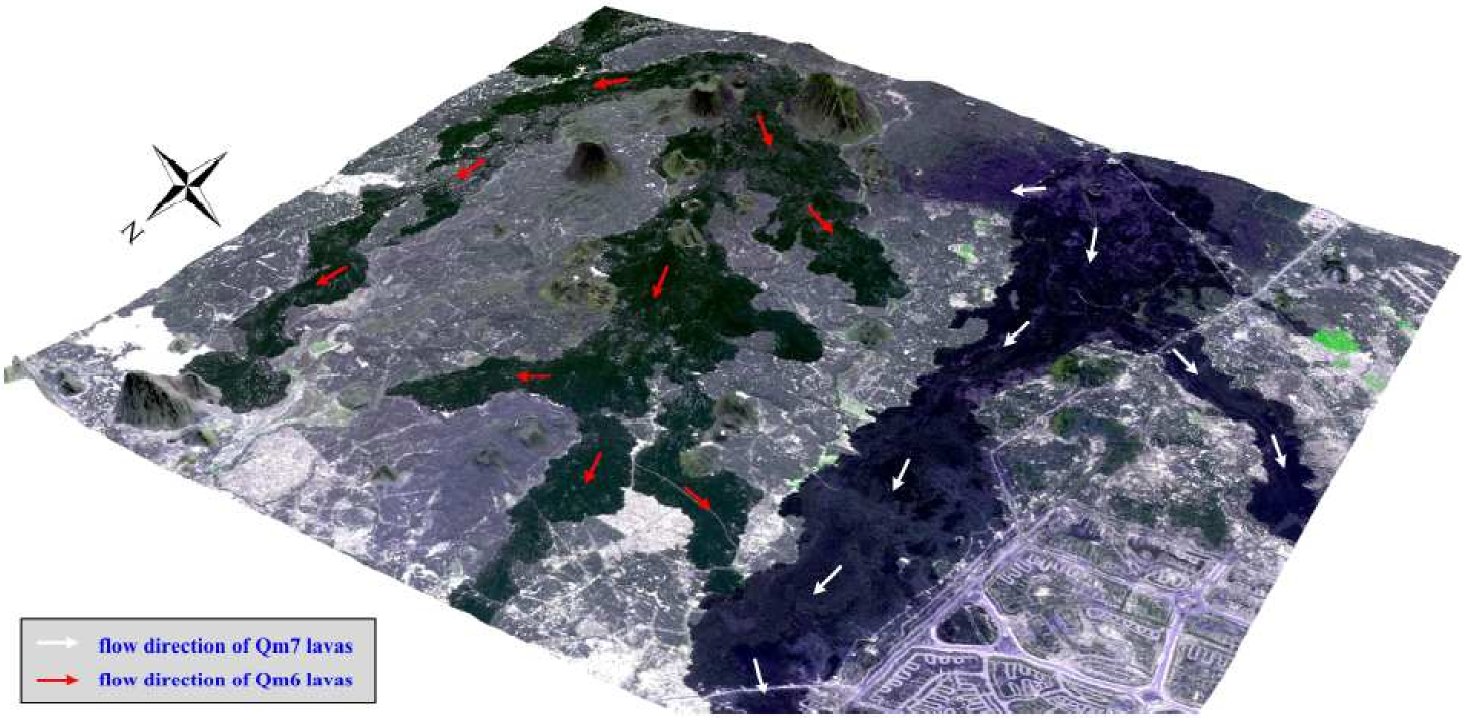

Figure 7

3D perspective view image reveals the different eruption periods and the flows direction in the north area of Medina volcanic field (view: WN-ES) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

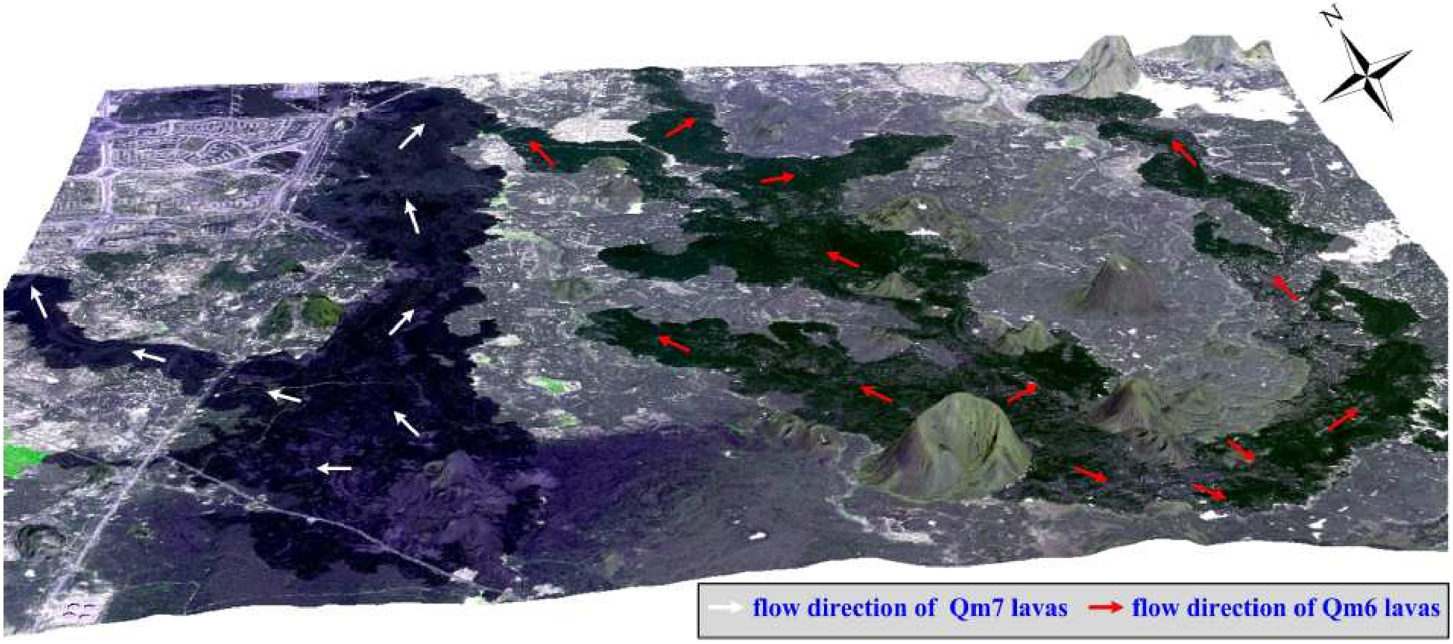

Figure 8

3D perspective view image reveals the different eruption periods and the flows direction in the north area of Medina volcanic field (view: N-S) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

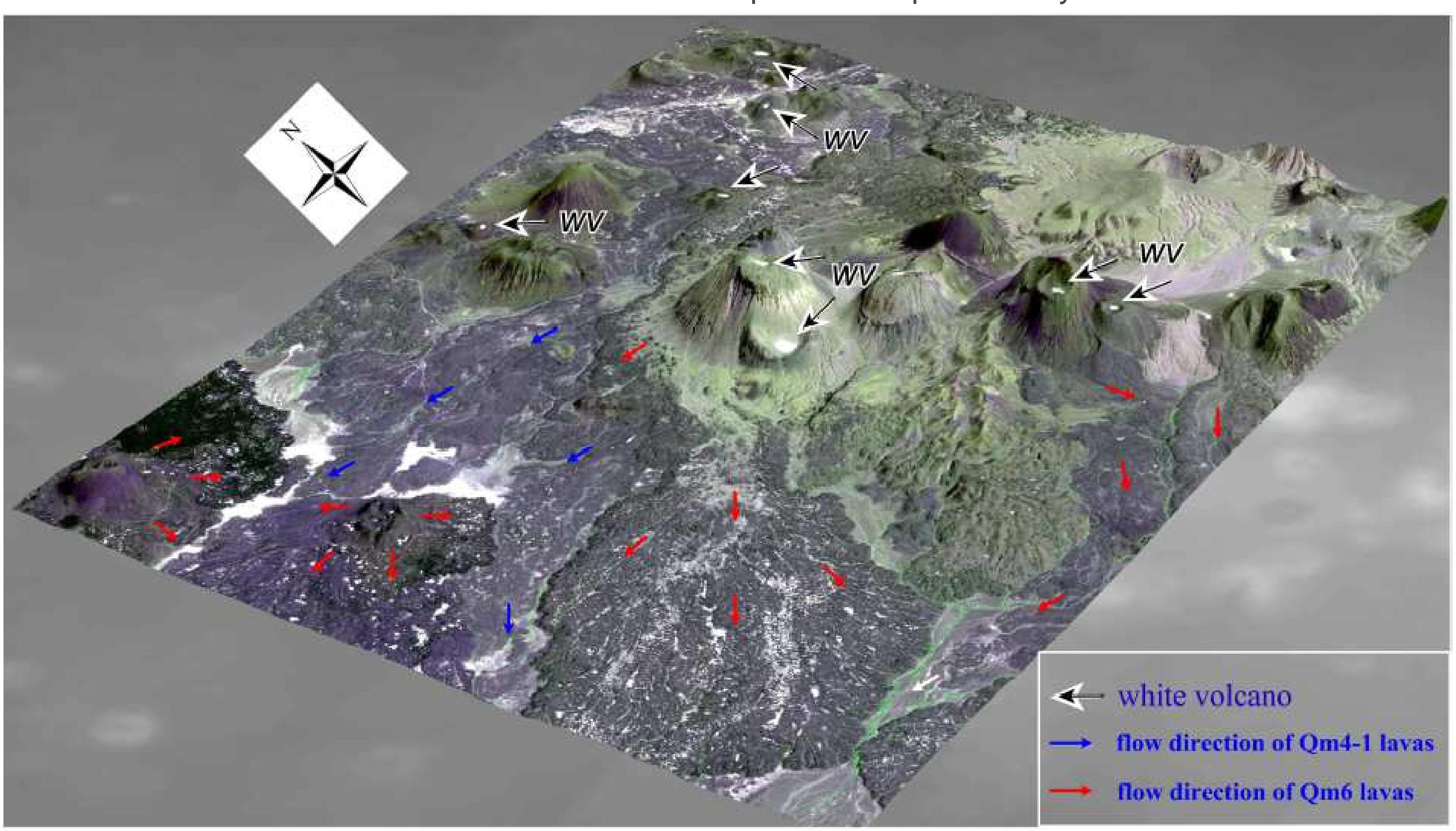

Figure 9

3D perspective view image reveals the different eruption periods and the flows direction in the south area of Medina volcanic field (view: WS-EN); WV means white volcano Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.