Volcano-tectonic architecture of Bioko Island (Equatorial Guinea) derived from TanDEM-X synthetic aperture radar data

Supplementary Material – Bulletin of Volcanology

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Documentation

All files and data created and calculated for this study, except the digital elevation model and the slope map, can be found on https://github.com/braunerj/Bioko. All geospatial data sets are projected in the coordinate reference system EPSG:32632 - WGS 84 / UTM zone 32N.

List of derivative files

Raster files
- digital_elevation_model.tif*
- slope_map.tif*
- vent_density.tif

* not publicly available but might be shared for future collaborations upon request

Generated vector files
- boundaries_bioko.shp (polygon)
- edifice_boundaries_calculated.shp (polygon)
- edifice_boundaries_manual.shp (polygon)
- vent_locations.shp (point)
- cones.shp (polygon)
- hot_spot.shp (polygon)
- rift_zones.shp (polygon)
- lineaments.shp (line)
- segments.shp (line)

Calculated shape factors
- Shape factors (major edifices)
- Shape factors (cones)

The listed files are described in detail in order of appearance below.

Digital elevation model

File name: digital_elevation_model.tif
Structure: Raster

The primary data source was a X-band TerraSAR-X (TSX) / TanDEM-X (TDX) synthetic aperture radar image product (Level 1B) with a nominal resolution of 3 m. The derived DEM (level 3 product) has a nominal resolution of 12 m and a relative height accuracy of 2 m for flat terrain and 4 m for slopes greater than 20°. The DEM is not publicly available, but might be shared on request for future collaborations upon request. The primary radar imagery and DEM was provided by the German Aerospace Center (DLR, 2021) based on the proposal DEM_GEOL3419.

Slope map

File name: slope_map.tif
Structure: Raster

The slope map was calculated with the Slope (Spatial Analyst) tool in ArcGIS® 10.8.1. The slope map is not publicly available, but might be shared on request for future collaborations upon request.

Vent density

File name: vent_density.tif
Structure: Raster

We calculated the vent density with the Point Density (Spatial Analyst) tool in ArcGIS® 10.8.1 with a cell size of 100m x 100m and a search radius of 1000m based on the mapped vent locations (vent_locations.shp). Therefore, the calculated raster data set represents the point- / vent-density in [1/km^2].

Boundary of Bioko Island

File name: boundaries_bioko.shp
Structure: Vector (polygon)
Attribute table header:
    id - ID

The boundary of Bioko Island was downloaded from OpenStreetMap:

https://osmdata.openstreetmap.de/data/coastlines
722017 LineString features
WGS84 geographic coordinates (EPSG: 4326)

Extent: (-180.000, -78.733) - (180.000, 83.666)
Date of the data used: 2021-03-02T01:00:00Z

This data is Copyright 2021 OpenStreetMap contributors. It is available under the Open Database License (ODbL). We used the data to clip the DEM in order to reduce the computational time for further processing.

Edifice boundaries (calculated)

File name: edifice_boundaries_calculated.shp
Structure: Vector (polygon)
Attribute table header:

- id - ID
- area - Area [m^3]
- points - Number of vents within the polygon

The edifice boundaries were calculated based on the NETVOLC algorithm by Euillades et al. (2013) in ENVI. The algorithm considers parameters such as convex breaks in the slope and aspect based on the provided DEM of a given volcano. The documentation as well as the software package can be found here: https://cediac.ingenieria.uncuyo.edu.ar/software/.

Edifice boundaries (manual)

File name: edifice_boundaries_manual.shp
Structure: Vector (polygon)
Attribute table header:

- id - ID
- area - Area [m^3]
- points - Number of vents within the polygon

The edifice boundaries were defined manually based on the assumption that the entire island consists of three coalescing volcanoes and therefore only the boundaries between the individual edifices needed to be determined. This was achieved by mapping the lines through the centers of the depressions between two adjacent volcanoes. The outlines were completed with the coastline (boundaries_bioko.shp).

Vent locations

File name: vent_locations.shp
Structure: Vector (point)
Attribute table header:

- id - ID
- breach – Indicates whether a mapped vent shows signs of breaching; y = breach detected, n = no breach detected, u = uncertain.
- X – Easting [m]
- Y – Northing [m]

We mapped vents manually using QGIS® 3.10.14. Referring to Tibaldi (1995), we distinguished between vents as discrete eruptive centers and monogenetic cones, which may comprise one or multiple vents.

Monogenetic cones

File name: cones.shp
Structure: Vector (polygon)
Attribute table header:
id - ID

We mapped monogenetic cone outlines manually using ENVI. Referring to Tibaldi (1995), we distinguished between vents as discrete eruptive centers and monogenetic cones, which may comprise one or multiple vents. Associated shape factors can be found in Appendix II (appendix_II.csv) and linked to the polygons via the included coordinates.

Hot Spot

File name: hot_spot.shp
Structure: Vector (polygon)
Attribute table header:
id - ID
points - Number of vents within the polygon
GiZScore - Z-scores are standard deviations.
GiPScore - The p-value is a probability. For the pattern analysis tools, it is the probability that the observed spatial pattern was created by some random process.
GI_Bin - The Gi_Bin field identifies statistically significant hot and cold spots. Features in the +/-3 bins reflect statistical significance with a 99 percent confidence level; features in the +/-2 bins reflect a 95 percent confidence level; features in the +/-1 bins reflect a 90 percent confidence level; and the clustering for features in bin 0 is not statistically significant.

In order to identify statistically significant hot spots of the previously mapped vents (vent_locations.shp), we performed the Hot Spot Analysis (Getis-Ord Gi*) tool in ArcGIS® 10.8.1. Therefore, we created a grid of rectangular cells (1 km x 1 km) with the Create Fishnet tool in ArcGIS® 10.8.1. In the next step we performed a Nearest Neighbour Analysis (611m; QGIS® 3.10.14). To include a meaningful number of neighboring points, we choose a distance band of 5000m for the Hot Spot Analysis (Getis-Ord Gi*).

Rift zones

File name: rift_zones.shp
Structure: Vector (polygon)
Attribute table header:
id - ID

We defined the rift zones manually in QGIS® 3.10.14 based on the 99 percent confidence level areas of the statistically significant hot spots (hot_spot.shp) with respect to the previously, manually mapped edifice outlines (edifice_boundaries_manual.shp).

Lineaments

File name: lineaments.shp
Structure: Vector (line)
Attribute table header:

- id - ID
- class - Class of lineaments (see table below)

(1) Lineaments related to volcano-tectonic processes			
(11) At the summit		(12) In the periphery	
(111) Caldera outlines - (sub-)circular structures bounding the rim of central volcanic depressions	(112) Summit grabens - parallel linear features characterized by a distinctive negative offset in elevation	(121) Peripheral structures - radial, concentric, or rift-parallel features at the flanks and base	(122) Peripheral + fluvial structures - straight line features; affected by fluvial erosion

(2) Lineaments related to monogenetic cones		
(21) Breach - central line through the collapsed flank and the center of a cone	(22) Major axes - long axes of the cone	(23) Alignments - prominent alignments of three or more cones

(3) Miscellaneous		
(31) Erosional calderas - outlines of erosional features at steep flanks of major volcanoes	(32) Orientation of erosional calderas - long axes of erosional features at steep flanks of major volcanoes	(33) Coastlines - anomalously straight sections of the coastline

For the line features, three main categories were defined and mapped manually (except class 22; not included in the attribute table) where each distinguishes sub-types based on origin and location (see table above). The major axes of the outlined monogenetic cones (cones.shp) were characterized with the MORVOLC algorithm in ENVI (Grosse et al., 2012). The calculated major axes complemented the dataset of mapped lineaments. To reduce processing time of the MORVOLC algorithm the DEM was resampled to 36 m per pixel. In order to create azimuth rose plots, we segmented the lineaments of the categories: 112, 121, 122, 31, 33.

Segments

File name: segments.shp
Structure: Vector (line)
Attribute table header:

- id - ID
- og_line_id - ID of the original ID (lineaments.shp)
- class - Class of lineaments (see table above)
- Start_X - Easting of start of line [m]
- Start_Y - Northing of start of line [m]
- End_X - Easting of end of line [m]
- End_Y - Northing of end of line [m]
- Seg_Length - Length of segment [m]
- Fwd_Azmth - Azimuth / degree from north clockwise [°]
- Rev_Azmth - Azimuth / degree from north clockwise + 180° [°]

For the line features (segmented), three main categories were defined and mapped manually (except class 22; not included in the attribute table) where each distinguishes sub-types based on origin and location (see also lineaments.shp). In order to create azimuth rose plots, we segmented the lineaments of the categories: 112, 121, 122, 31, 33.

Shape factors for major edifices

File name: OnlineResource2.csv
Structure: Table (csv)

The morphometry of the outlined edifices (edifice_boundaries_manual.shp) were characterized with the MORVOLC algorithm in ENVI (Grosse et al., 2012). The documentation as well as the software package can be found here: https://cediac.ingenieria.uncuyo.edu.ar/software/.

Shape factors of cones

File name: OnlineResource3.csv
Structure: Table (csv)

The morphometry of the outlined monogenetic cones (cones.shp) were characterized with the MORVOLC algorithm in ENVI (Grosse et al., 2012). The documentation as well as the software package can be found here: https://cediac.ingenieria.uncuyo.edu.ar/software/.

References

Euillades, L. D., Grosse, P., & Euillades, P. A. (2013). NETVOLC: an algorithm for automatic delimitation of volcano edifice boundaries using DEMs. Computers & Geosciences, 56, 151-160.

Grosse, P., De Vries, B. V. W., Euillades, P. A., Kervyn, M., & Petrinovic, I. A. (2012). Systematic morphometric characterization of volcanic edifices using digital elevation models. Geomorphology, 136(1), 114-131.

OSM (2021). OpenStreetMap project - LineString features of coastline of Bioko Island downloaded from https://osmdata.openstreetmap.de/data/coastlines on 2021-03-02.

Tibaldi, A. (1995). Morphology of pyroclastic cones and tectonics. Journal of Geophysical Research: Solid Earth, 100(B12), 24521-24535.