Section: Earth Sciences through Earth Observation

Natural Hazard Assessment in Western Saudi Arabia using Remote Sensing and GIS Methods

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Natural Hazard Assessment in Western Saudi Arabia using Remote Sensing and GIS Methods

1. Introduction

Overview of the different Natural Hazards

2. Methods and Workflow

Digital Image Processing of Satellite Data
Digital Processing of Digital Elevation Data

3. Results of the GIS integrated Evaluations of Satellite Data

Weighted Overlay for the Detection of Areas Susceptible to Slope Failure
Digital Image Processing of Satellite Data and Evaluations

4. Conclusions

Overview of the different Natural Hazards

Western Saudi Arabia is prone to different natural hazards such as earthquakes, tsunamis and volcanic hazards, as well as flash floods after heavy rainfalls. Slope failure, especially rock fall, is a common phenomenon in the mountainous regions. Shifting sand dunes and dust storms are a serious natural hazard being faced.

An inventory of past geohazards is one of the main prerequisites for an objective hazard assessment. Such a hazard assessment requires a multi-source, systematic record.

The ability to undertake the assessment, monitoring and modeling can be improved to a considerable extent through the current advances in remote sensing and GIS technology.

This is demonstrated in the scope of this research by the following examples:

- Flooding: Detection of areas prone to flash floods
- Seismic hazards: Mapping of traces fault and fracture zones and of structural features based on remote sensing data
- Volcanism: Inventory of volcanic features
- Tsunami hazards: Detection of areas prone to tsunami flooding

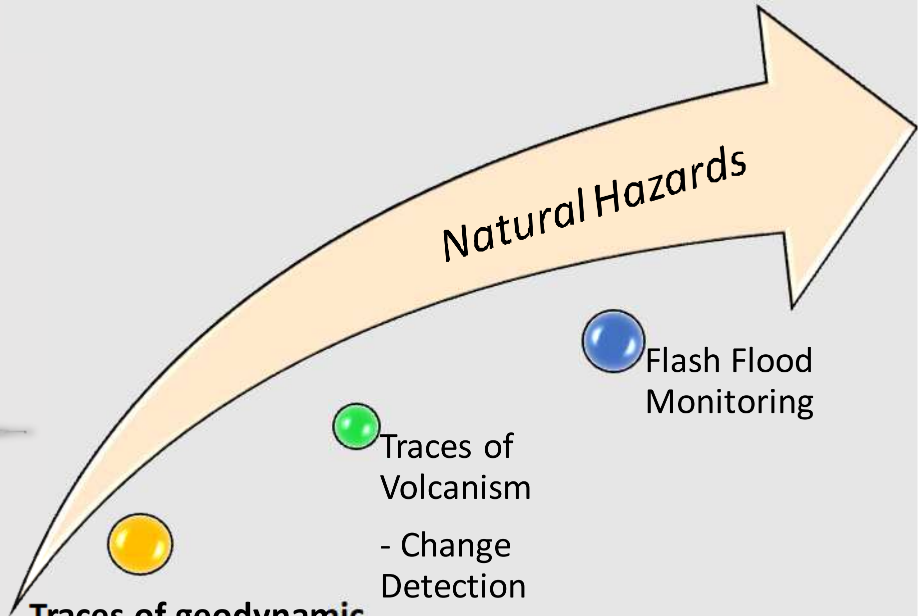
1. Introduction: Overview of the different Natural Hazards

Natural Hazards in W-Saudi Arabia

- Flashfloods
- Geodynamic movements due to plate tectonic activity
- Earthquakes and earthquake induced secondary effects (mass movements, compaction of soils, tsunami waves)
- Volcanism
- Dust Storms
- Slope failure
  Earth flow, debris flow, gully erosion
- Salt Tectonics
- Karst

- **Climate Change**
  increasing intensity of extreme weather events such as flashfloods and dust storms

Focus of Research based on Remote Sensing and GIS Methods



Flash Flood Monitoring

Traces of Volcanism

- Change Detection

Traces of geodynamic movements

Lineament Analysis
Traces of compression

Mapping of fault zones

Structural evaluations

Mapping of escarpments, terraces

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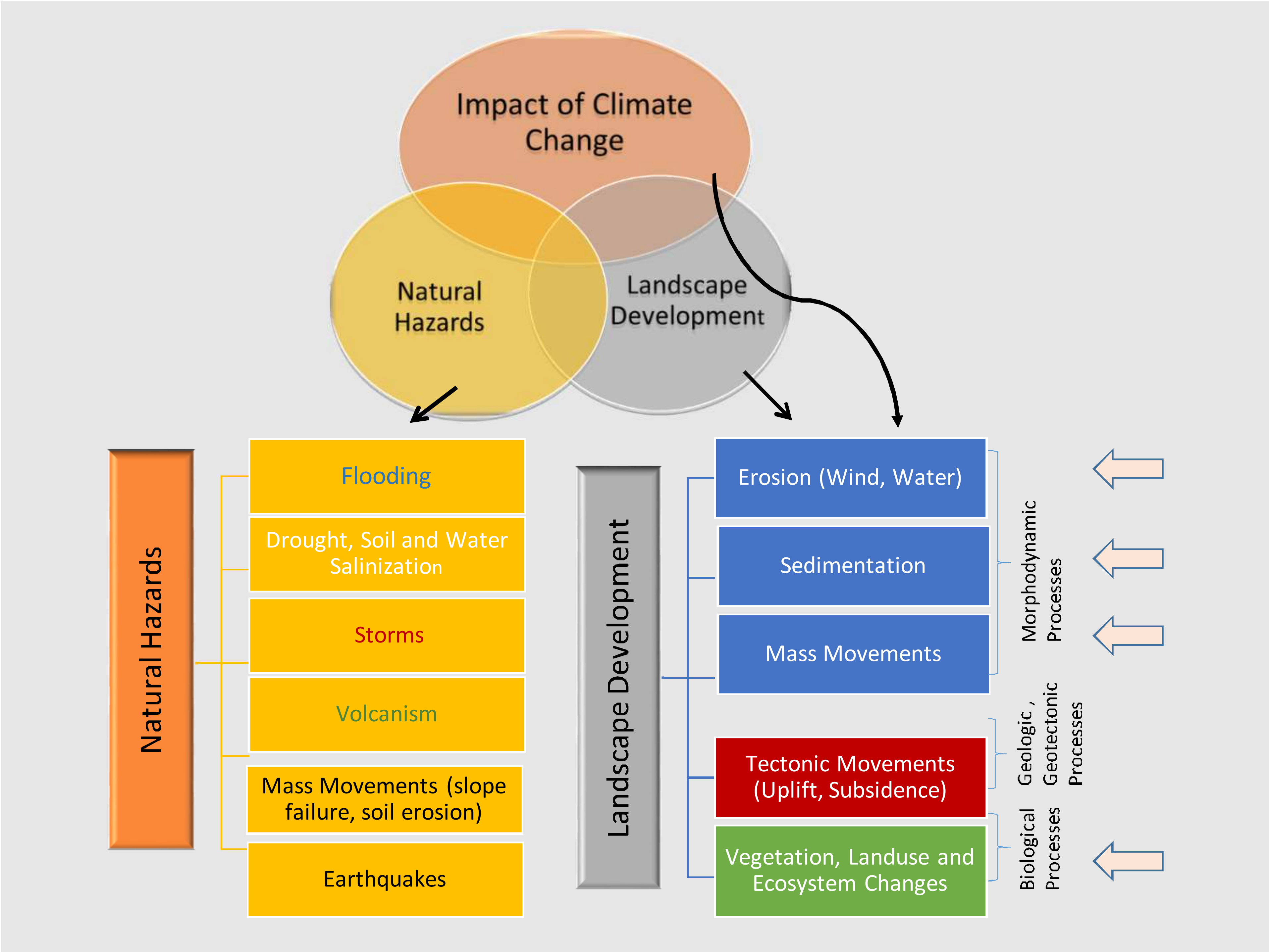

Impact of Climate Change
Natural Hazards
Landscape Development
Natural Hazards
Flooding
Drought, Soil and Water Salinization
Storms
Volcanism
Mass Movements (slope failure, soil erosion)
Earthquakes
Landscape Development
Erosion (Wind, Water)
Sedimentation
Mass Movements
Tectonic Movements (Uplift, Subsidence)
Vegetation, Landuse and Ecosystem Changes
Morphodynamic Processes
Geologic, Geotectonic Processes
Biological Processes

2. Methods and Workflow

Digital Image Processing of Optical and Radar Satellite Data

- RGB
- NDWI-Wasser-Index for soil moisture detection
- Principal Component, classifications
- Filter techniques (Morphologic Convolution)

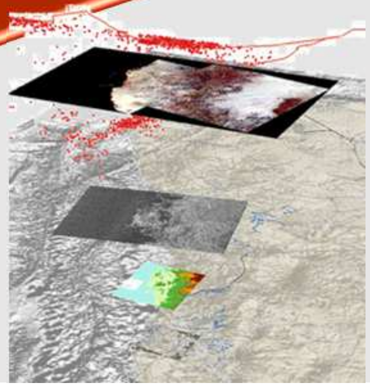
GIS integrated Evaluation of Satellite Data

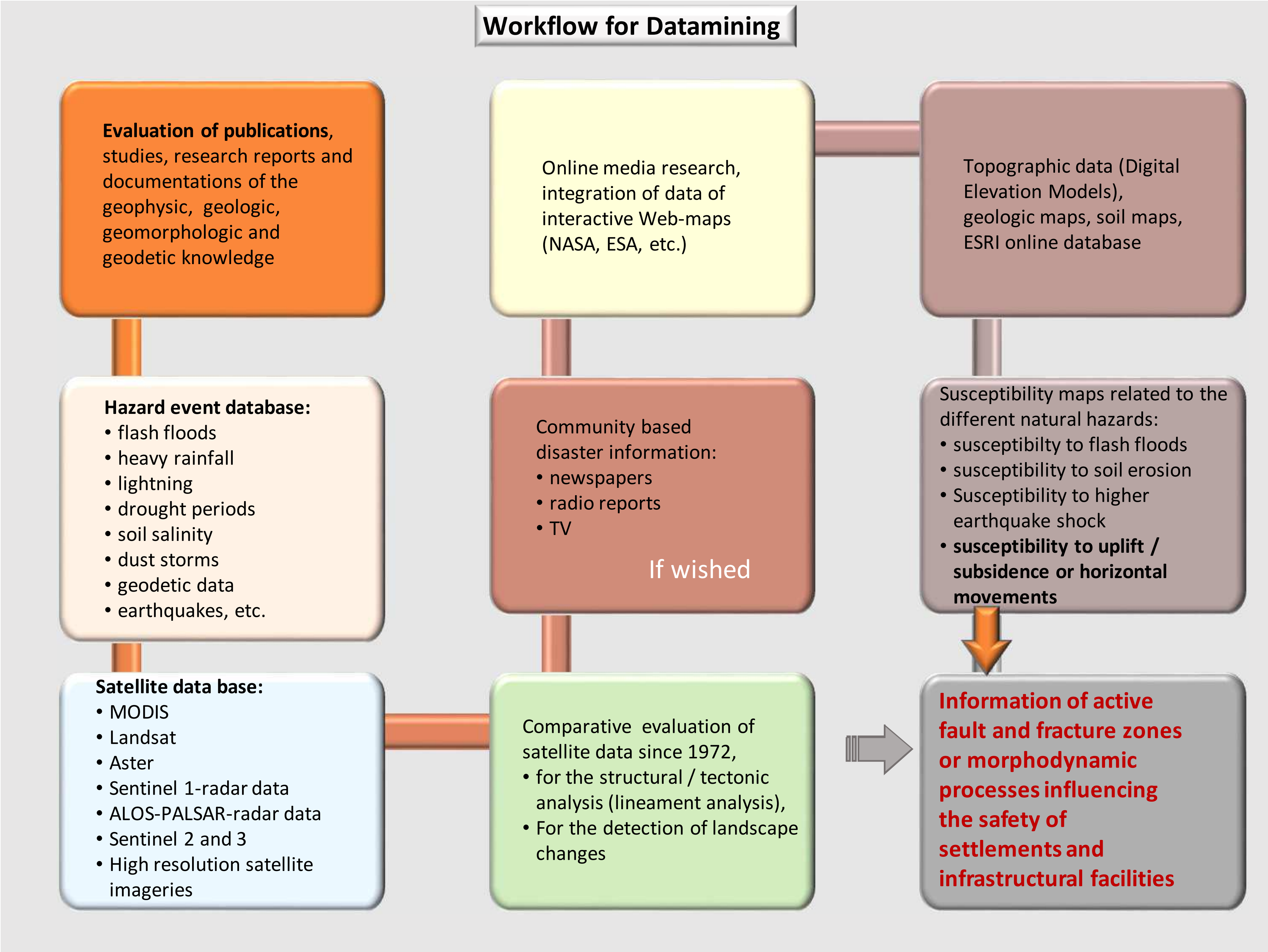
- Extraction of areas with higher soil moisture
- Lineament analysis
- Weighted Overlay

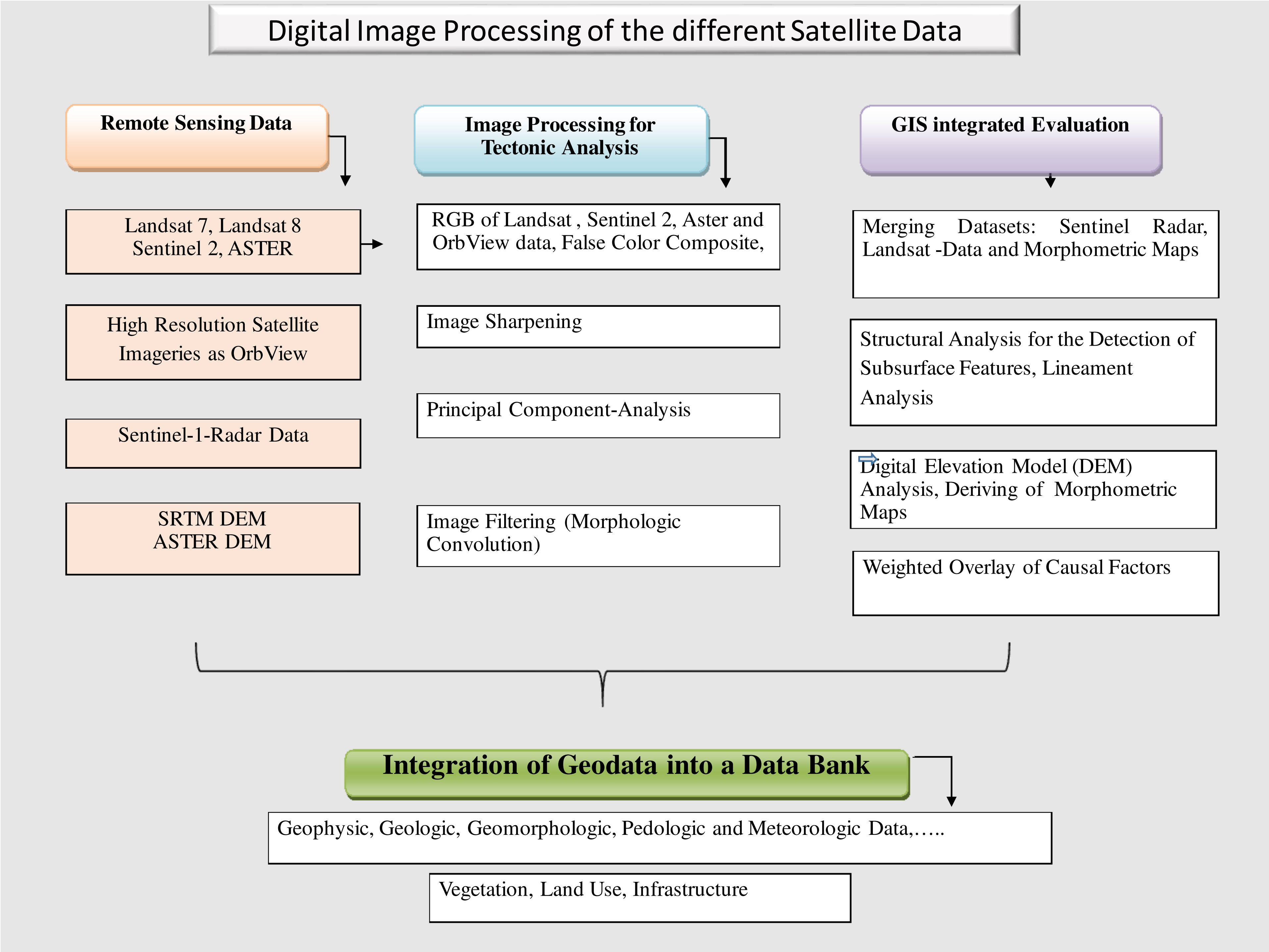
Integration and Combination of Geodata

- Integration of geophysic, geologic, geomorphologic and pedologic data
- Digital Elevation Data (DEM)
- Vegetation, land use, infrastructure

- Multi-source, systematic Record
- Hazard Assessment
- Creation of a Data Bank



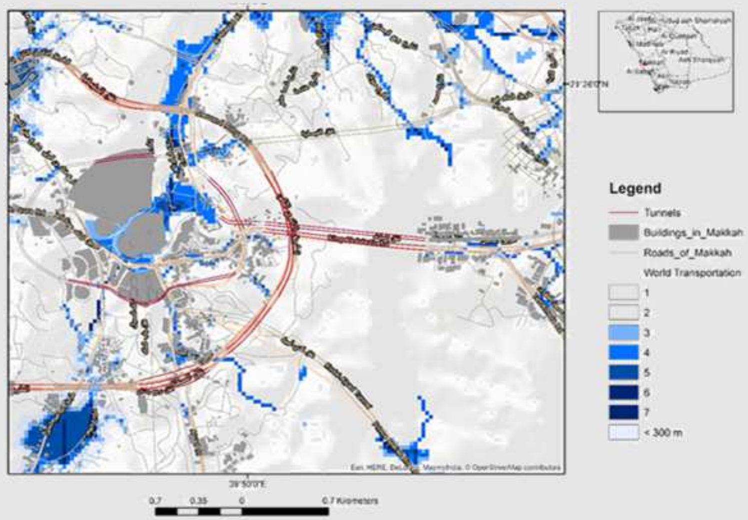

Workflow for Datamining
Evaluation of publications, studies, research reports and documentations of the geophysic, geologic, geomorphologic and geodetic knowledge
Online media research, integration of data of interactive Web-maps (NASA, ESA, etc.)
Topographic data (Digital Elevation Models), geologic maps, soil maps, ESRI online database
Hazard event database:
• flash floods
• heavy rainfall
• lightning
• drought periods
• soil salinity
• dust storms
• geodetic data
• earthquakes, etc.
Community based disaster information:
• newspapers
• radio reports
• TV
If wished
Susceptibility maps related to the different natural hazards:
• susceptibilty to flash floods
• susceptibility to soil erosion
• Susceptibility to higher earthquake shock
• susceptibility to uplift / subsidence or horizontal movements
Satellite data base:
• MODIS
• Landsat
• Aster
• Sentinel 1-radar data
• ALOS-PALSAR-radar data
• Sentinel 2 and 3
• High resolution satellite imageries
Comparative evaluation of satellite data since 1972,
• for the structural / tectonic analysis (lineament analysis),
• For the detection of landscape changes
Information of active fault and fracture zones or morphodynamic processes influencing the safety of settlements and infrastructural facilities


Digital Image Processing of the different Satellite Data
Remote Sensing Data
Landsat 7, Landsat 8
Sentinel 2, ASTER
High Resolution Satellite Imageries as OrbView
Sentinel-1-Radar Data
SRTM DEM
ASTER DEM
Image Processing for Tectonic Analysis
RGB of Landsat , Sentinel 2, Aster and OrbView data, False Color Composite,
Image Sharpening
Principal Component-Analysis
Image Filtering (Morphologic Convolution)
GIS integrated Evaluation
Merging Datasets: Sentinel Radar, Landsat -Data and Morphometric Maps
Structural Analysis for the Detection of Subsurface Features, Lineament Analysis
Digital Elevation Model (DEM) Analysis, Deriving of Morphometric Maps
Weighted Overlay of Causal Factors
Integration of Geodata into a Data Bank
Geophysic, Geologic, Geomorphologic, Pedologic and Meteorologic Data,…..
Vegetation, Land Use, Infrastructure

REMOTE SENSING AND GIS EVALUATION RESULTS FOR THE DETECTION AND MONITORING OF AREAS PRONE TO NATURAL HAZARDS

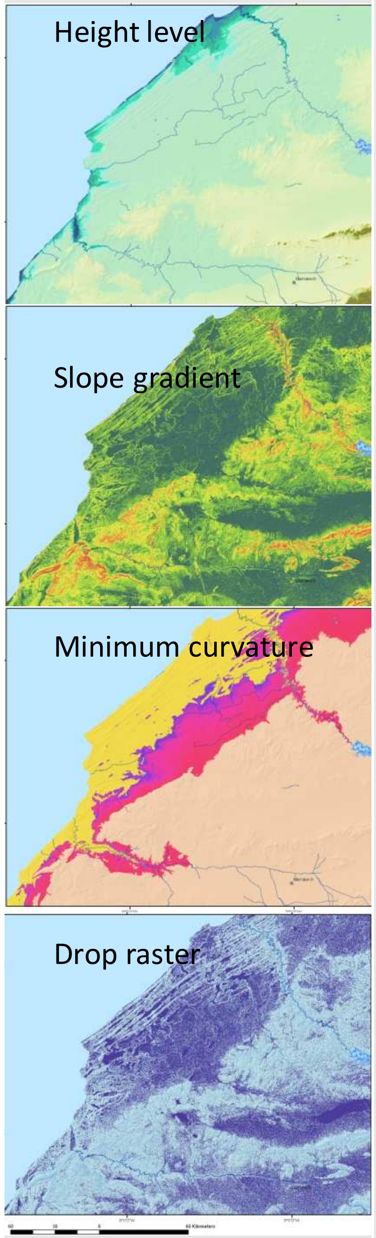
using the Examples of Flash Floods

Documentation of past hazards

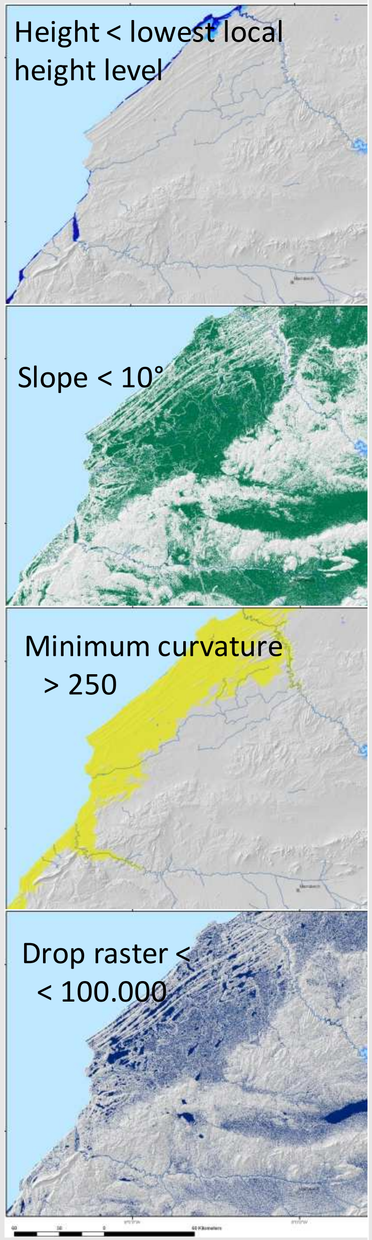


Detection of areas susceptible for future hazards

Contribution to the preparedness and adaption to impacts of climate change



Selection and extraction of attributes



factors influencing the susceptibility to soil amplification

Processing of Digital Elevation Model (DEM) Data

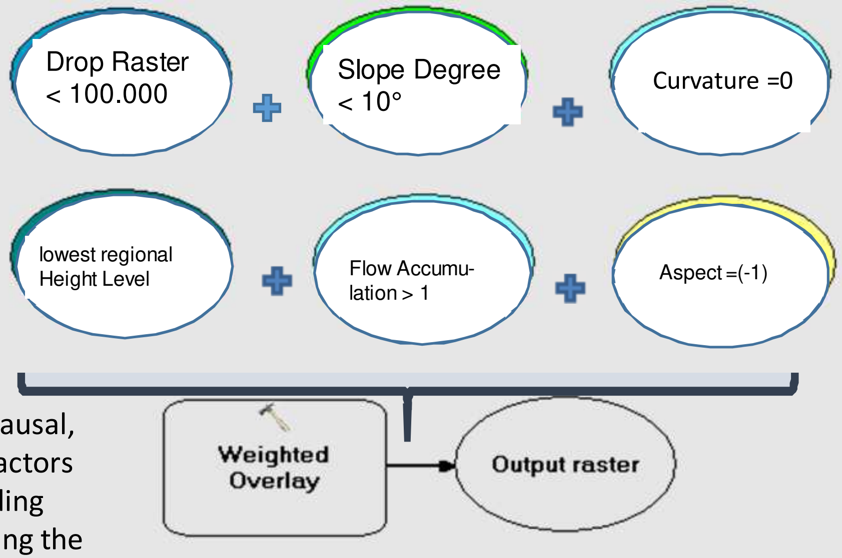
Extraction of causal / preparatory factors influencing the susceptibility to geohazards

- Deriving and extracting causal or preparatory factors from Digital Elevation Data (SRTM, ASTER, ALOS PALSAR- DEM)
- Aggregation of Layers in ESRI-Grid-Format

Susceptibility Map based on the Weighted Overlay Method in ArcGIS based on ASTER DEM Data

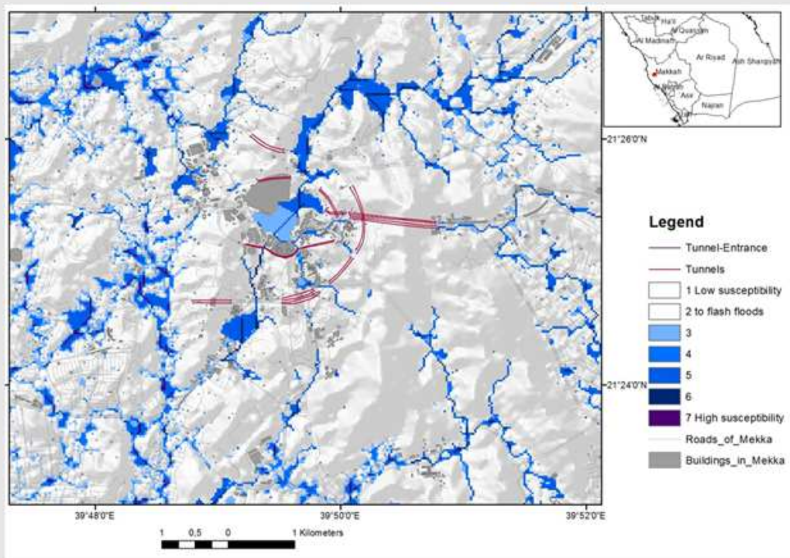
The resulting maps are divided into **susceptibility classes**. The susceptibility to soil amplification is classified by values from 0 to 6, whereby **the value 6 i**s standing for the **highest, assumed susceptibility due to the aggregation of causal / preparatory factors**.

Workflow of the Weighted Overlay of Causal / Preparatory Factors influencing the Flooding Susceptibility



Aggregation of causal, morphometric factors influencing flooding susceptibility using the weighted overlay-tool in ArcGIS

Result of the weighted overlay calculation



The resulting maps are divided into **susceptibility classes**. The susceptibility to flooding is classified by values from 0 to 6 or 7, whereby **the value 6 is** standing for the **highest, assumed susceptibility due to the aggregation of causal / preparatory factors**.

The weighted overlay approach in a GIS can be used for the detection and identification of endangered lowland areas susceptible to flooding. *Due to the aggregation of the below mentioned, morphologic factors these areas are more susceptible to flooding than the environment in case of flash floods.*

Based on SRTM, ASTER ALOS PALSAR Digital Elevation (DEM) data the following morphometric factors are extracted and then aggregated in the weighted overlay tool of ArcGIS:

- Lowest, local height levels
- flat terrain, calculating terrain curvature (curvature values= 0 , calculated in ArcMap, minimum curvature > 250 , calculated in ENVI)
- slope gradients < 10°
- drop raster < 100.000 and
- high flow accumulation values
- aspect = flat (-1)

Flash Floods

The holy capital of the Islamic religion is the ancient and beautiful city of Mecca. Located in the desert climate of Saudi Arabia, with temperatures often exceeding 45 degrees Celsius, this is the last place you would expect to experience heavy floods.

However, since the city is located in a low-lying region it is threatened by seasonal flash floods despite the low amount of annual rainfall. A flash flood is a very rapid flooding event often occurring with little warning.

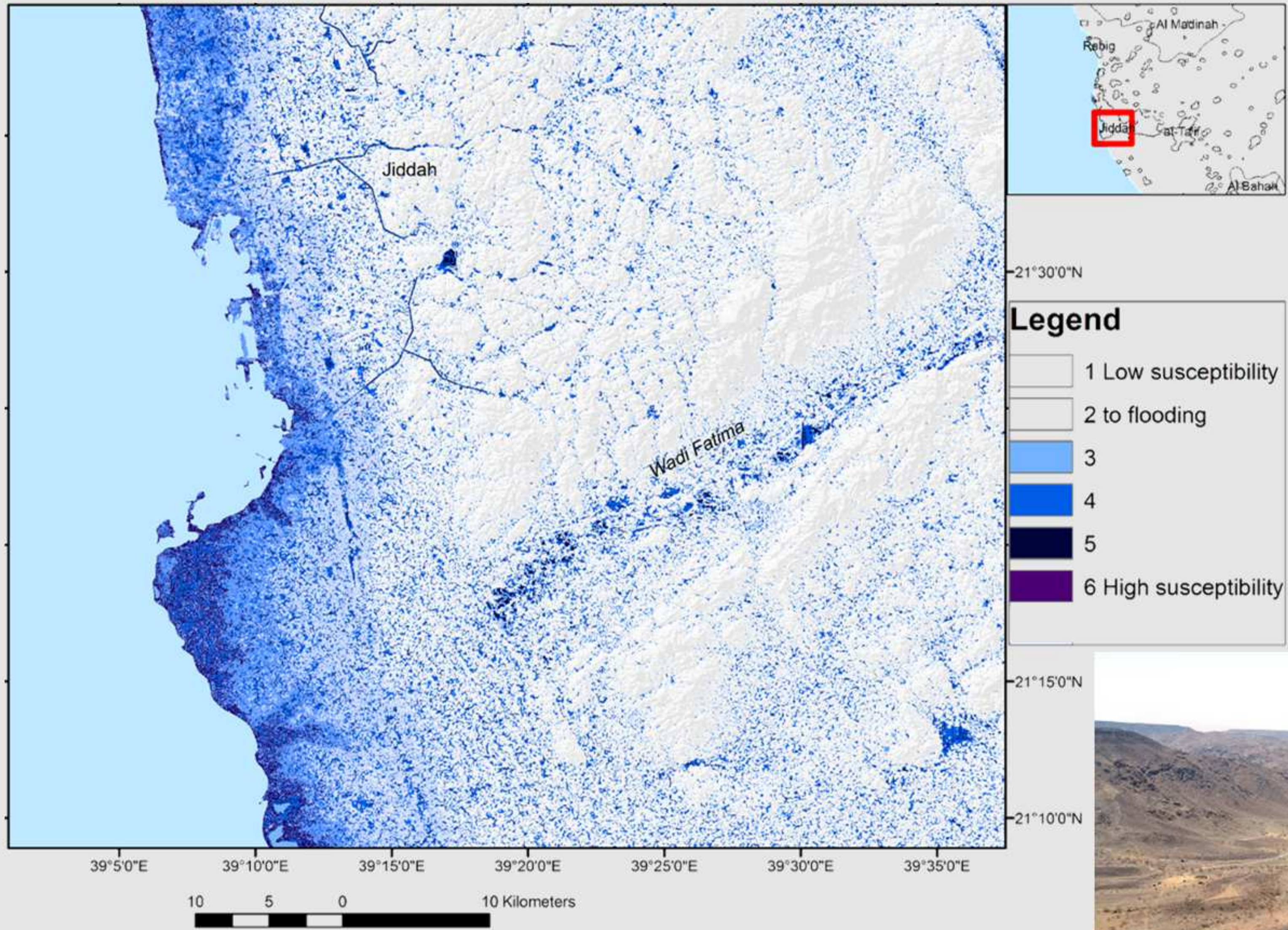
Heavy rainfall over the past week has resulted in significant flash floods in the city of Mecca today. At the time of writing the floods are ongoing. The pictures below show streets inundated by flood waters and a number of vehicles being swept away by the currents.

All images courtesy of Zakhir Hussain (09.05.2014).

https://climateandgeohazards.files.wordpress.com/2014/05/img-20140509-wa0008.jpg
https://www.facebook.com/ThePaleBlueDot.101/videos/463712447107420/

3. Results of the GIS integrated Evaluations of the Satellite Data

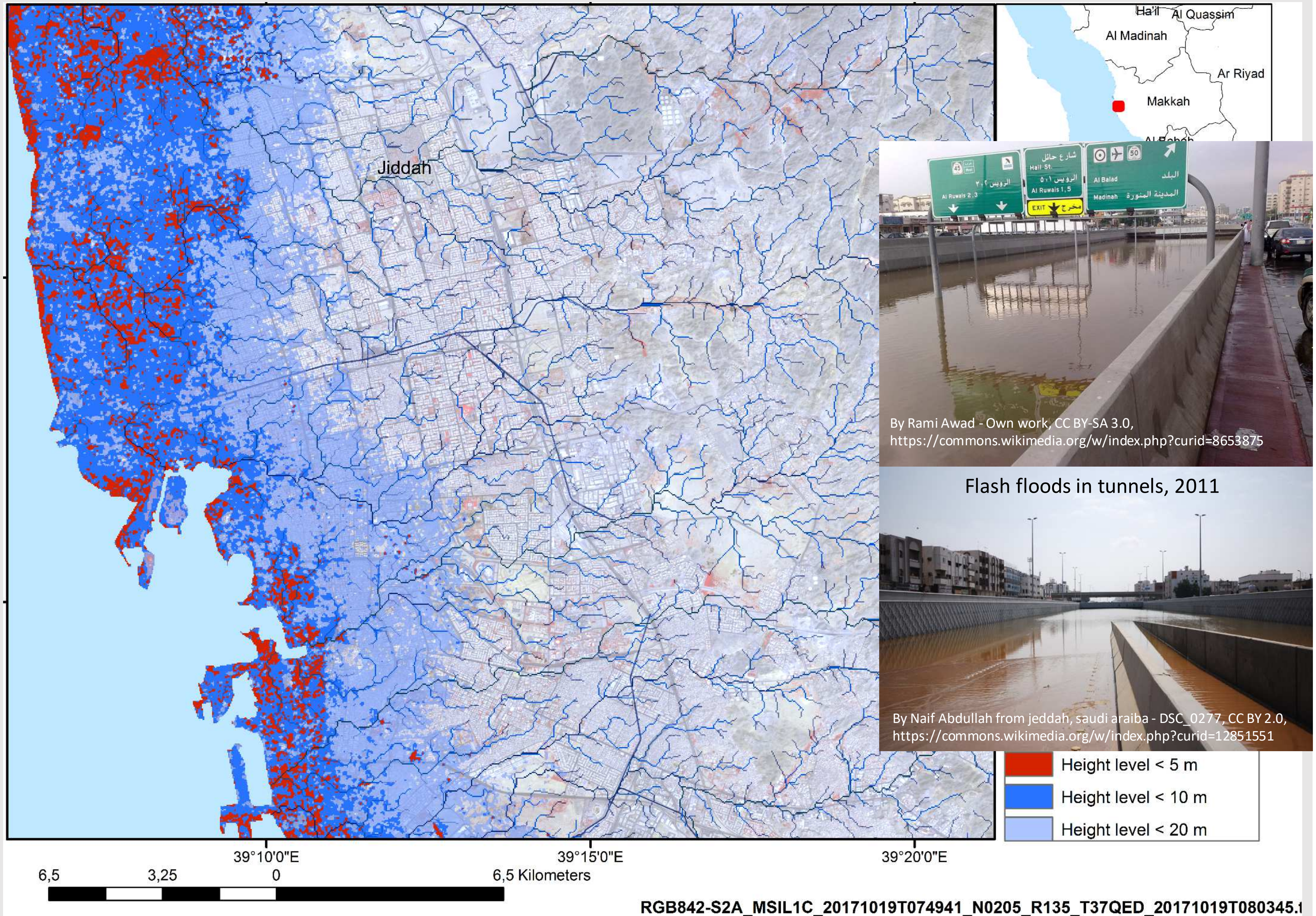
Areas susceptible to Flash Floods due to their morphometric Disposition



Weighted overlay of morphometric factors influencing the susceptibility to flooding by flash floods in the area of Jiddah, factors: curvature = 0, slope degree < 10°, height level < 10 m, dropraster < 100.000 (calculated in ArcGIS), flow accumulation > 5000

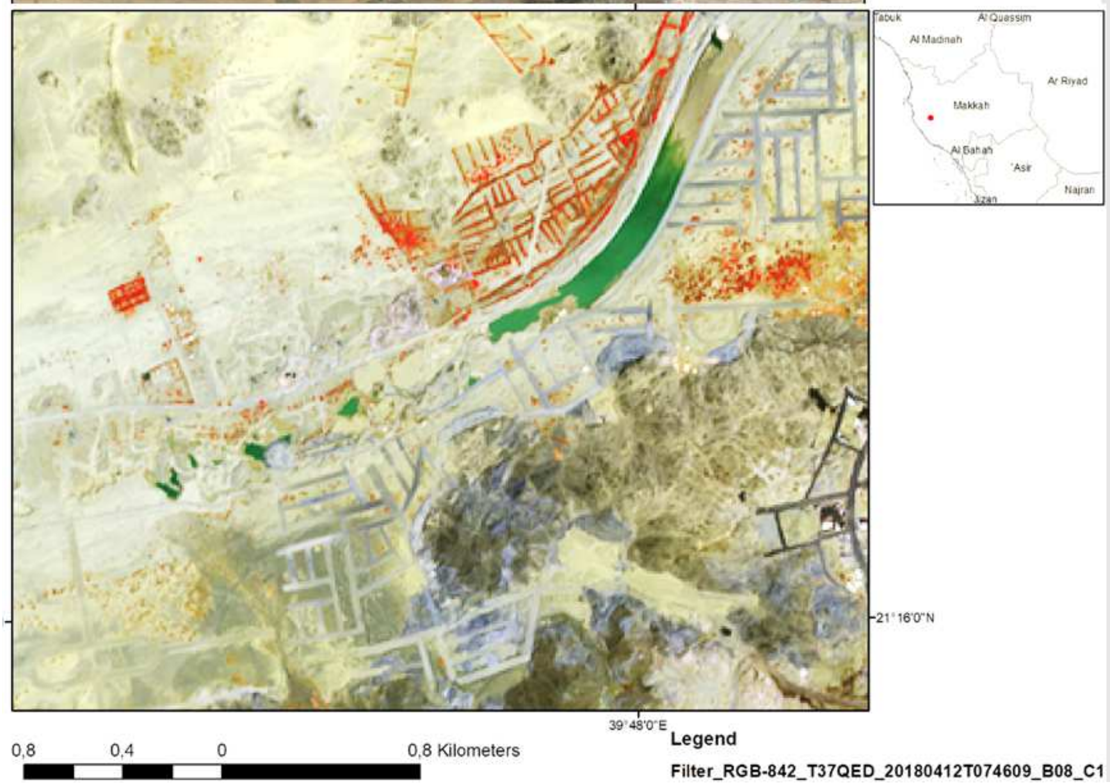
The picture of Wadi Fatima was taken by the photographer Geosergio on 16 March 2014 and published over Panoramio.

Height Levels and Stream Order in Jeddah



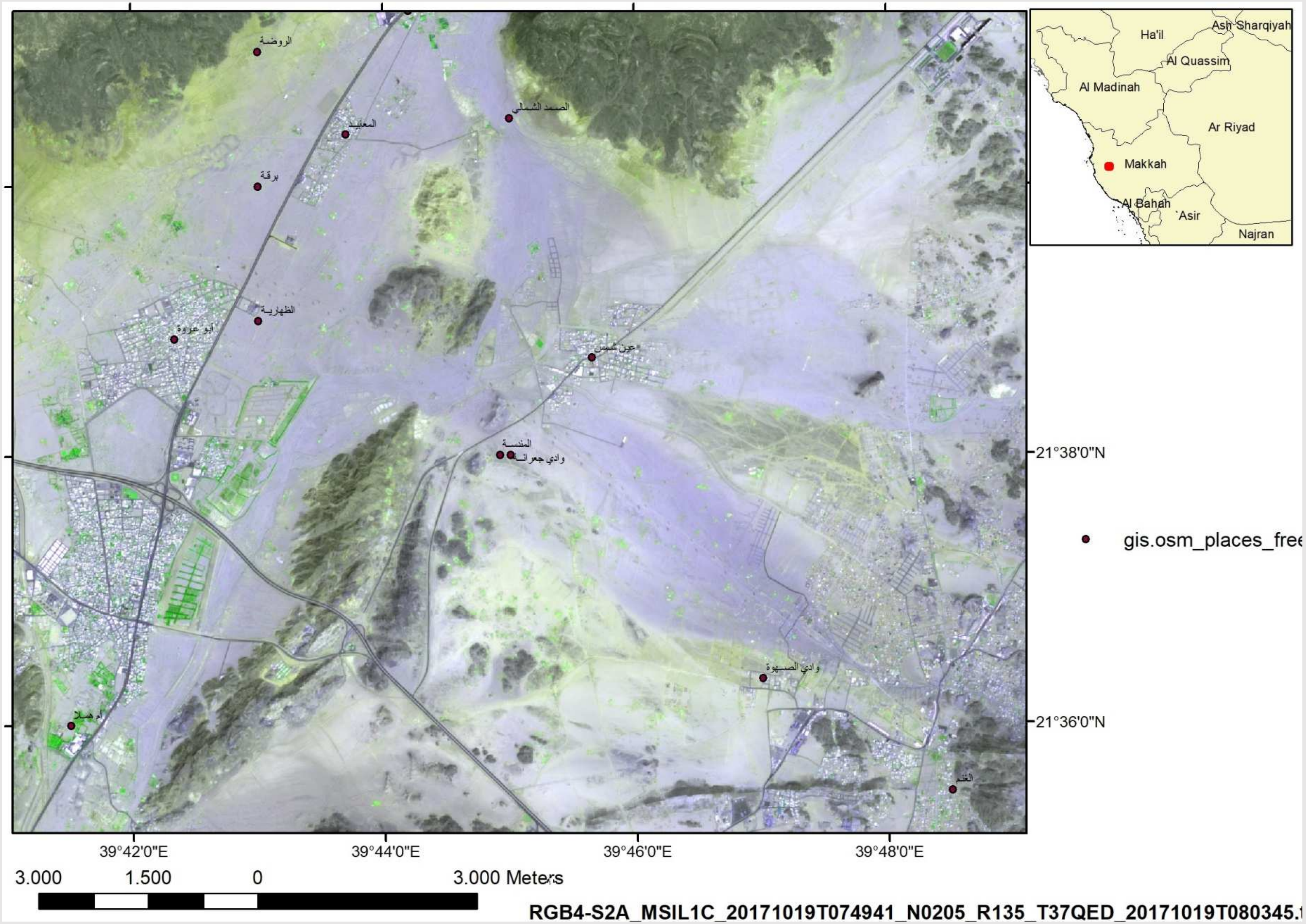
Flash Flood in 11 th of April 2018 in the Makkah-Region

Bing Map-scene acquired during a dry season



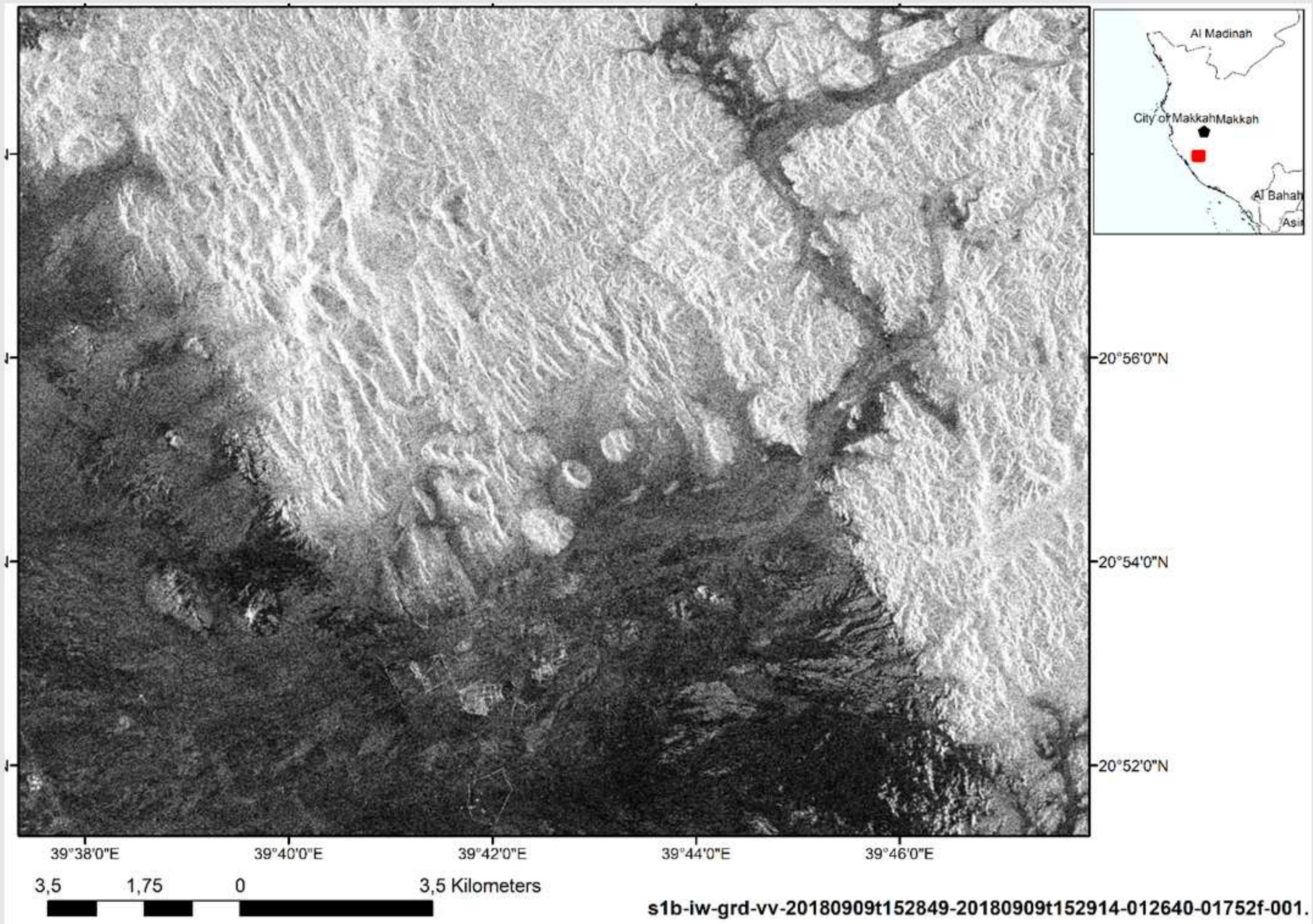
Sentinel-2-scene 12 th of April 2018 showing the still flooded areas in green colours

Sediment flow (light-blue) after heavy rains visible on a Sentinel 2-scene (date: 19.10.2017)



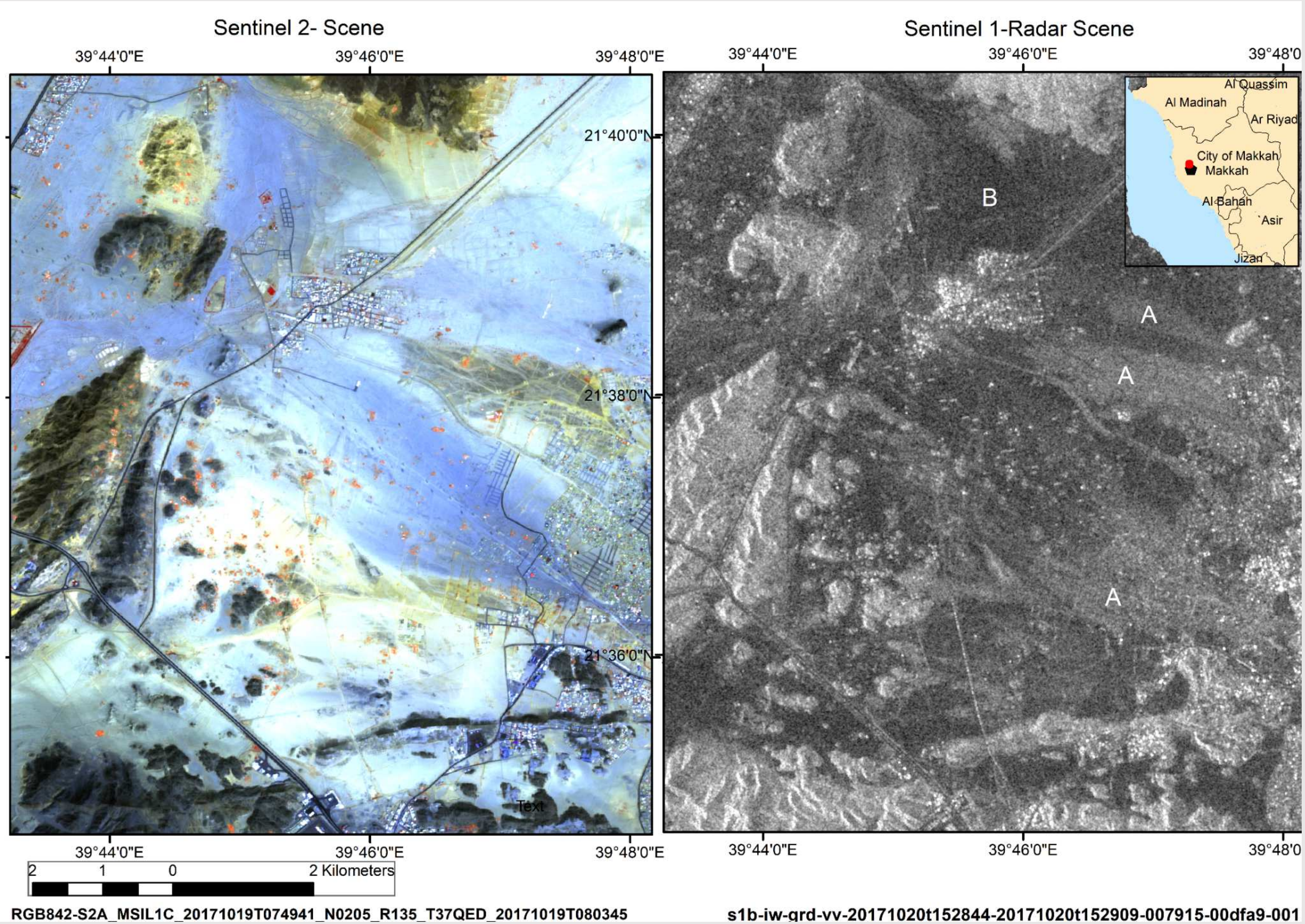
The monitoring and mapping of flash flood sediments and erosion pattern is an important issue for the planning of settlements, infrastructure and supply lines. Satellite images taken after the flash flood events help to identify areas affected by sediment flow and disposition.

Deriving Information of Sediment Properties from Radar Data



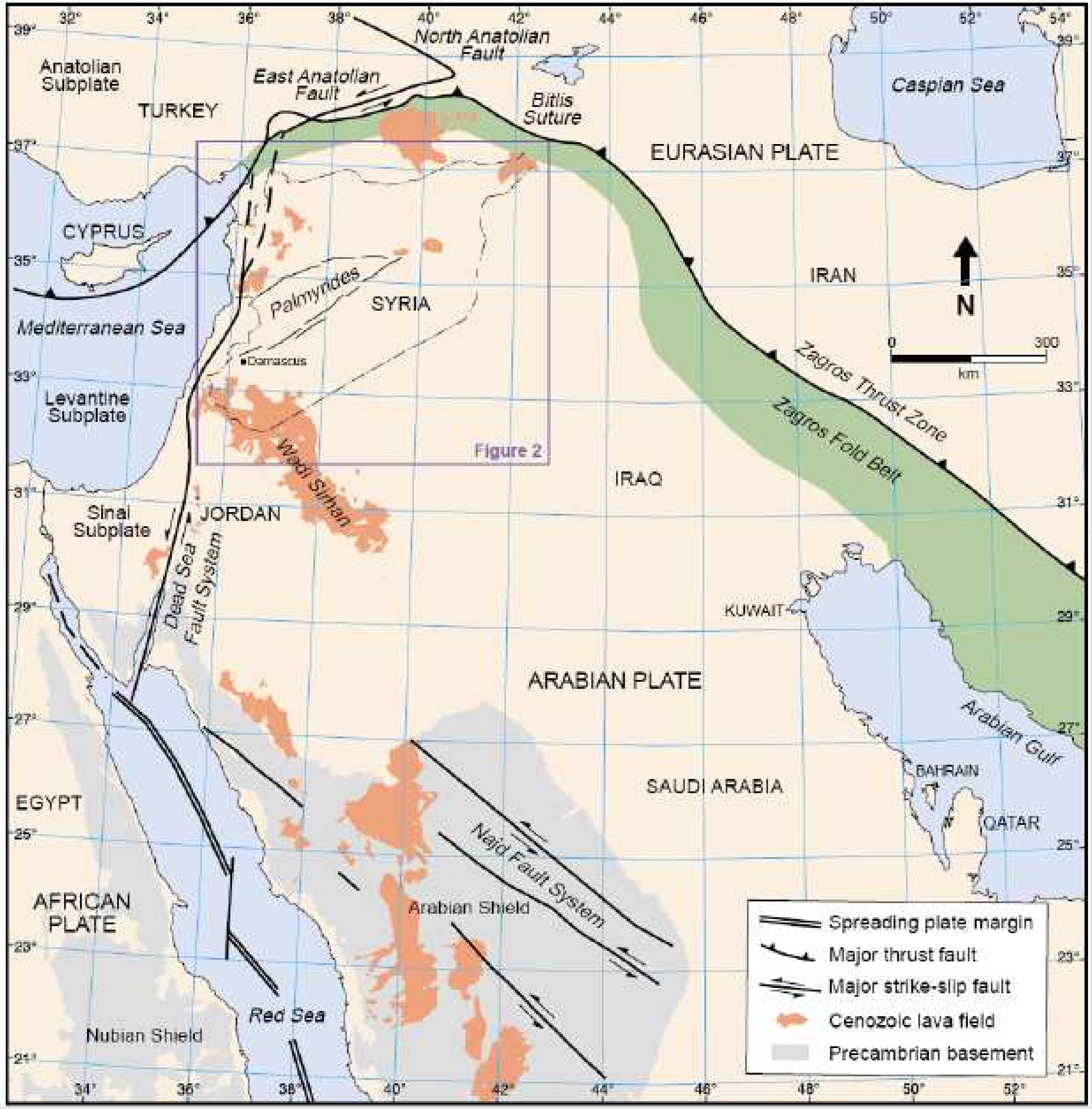
The differences in brightness between pixels in the radar image, marked by changes in the gray scale and backscatter intensity due to surface roughness changes contribute to the detection of **sediment properties.** Dark image tones are associated with finer grained sediment sheets (clay, sand) because the incident radar signals were largely reflected from their "radar-smooth" surfaces in a mirror-like fashion away from the satellite antenna. Coarse-grained sediments appear in lighter tones as their more radar-rough surfaces generate a diffuse and stronger signal return / radar backscatter. As the distance to the source areas of the transported sediments during a flash flood is relatively short in this area, coarse-grained, loose gravel seems to be prevailing, thus, causing the brighter tones on the radar image (diffuse radar backscatter). The finer grained material is transported to the larger valley towards the coastal area, where it is affected by aeolian activity forming dune fields.

Satellite Images taken after heavy Rains with Flash Floods (October 2017)



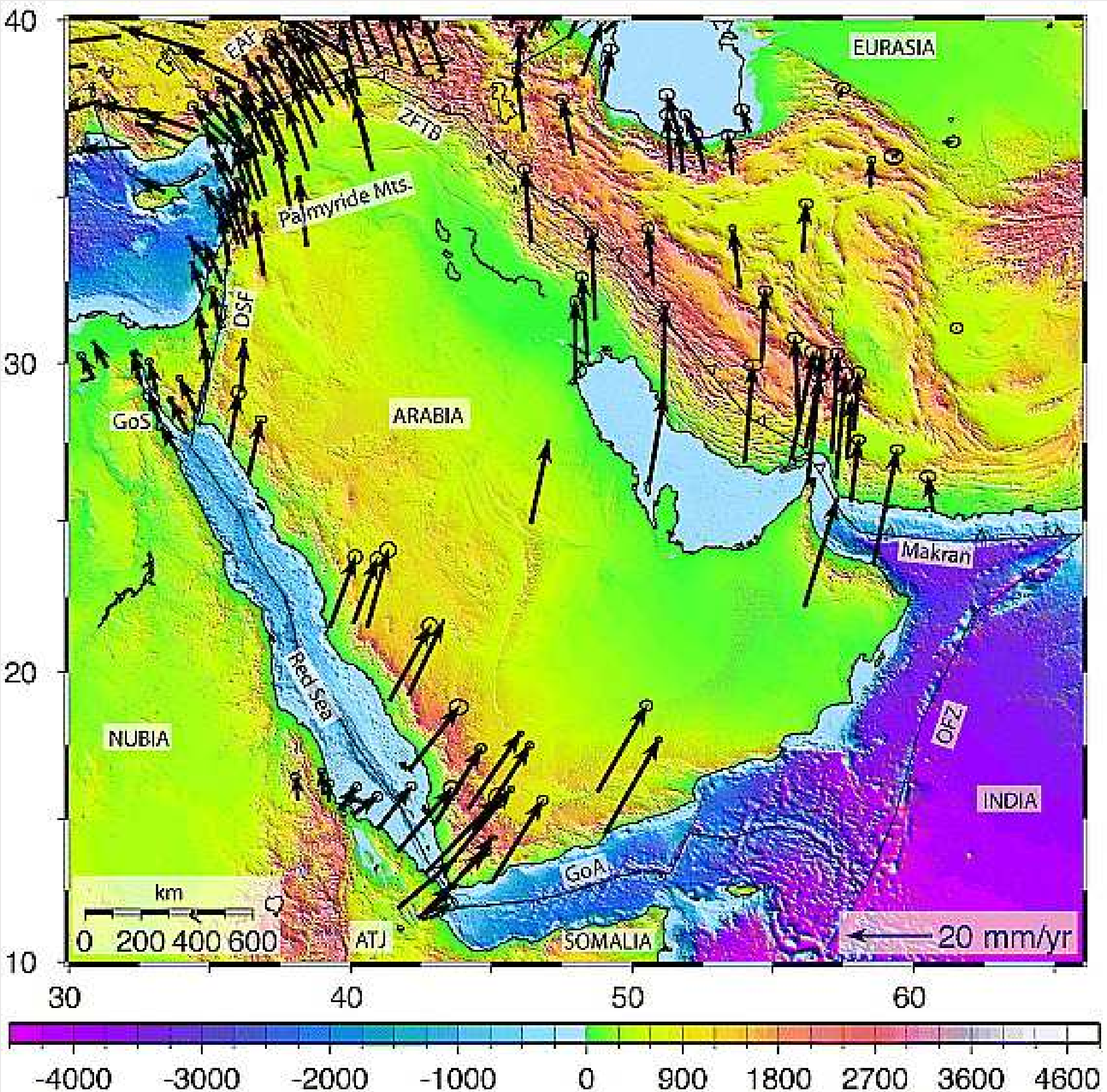
Sediment (blue colors) after heavy rains visible on a Sentinel 2-scene (acquisition date: 19.10.2017) and on the Sentinel 1 radar scene (acquisition date: 20.10.2017) west of the City of Mecca, A – coarser-grained sediments, B – finer grained sediments

Plate Tectonic Movements, Earthquakes and Volcanic Hazards

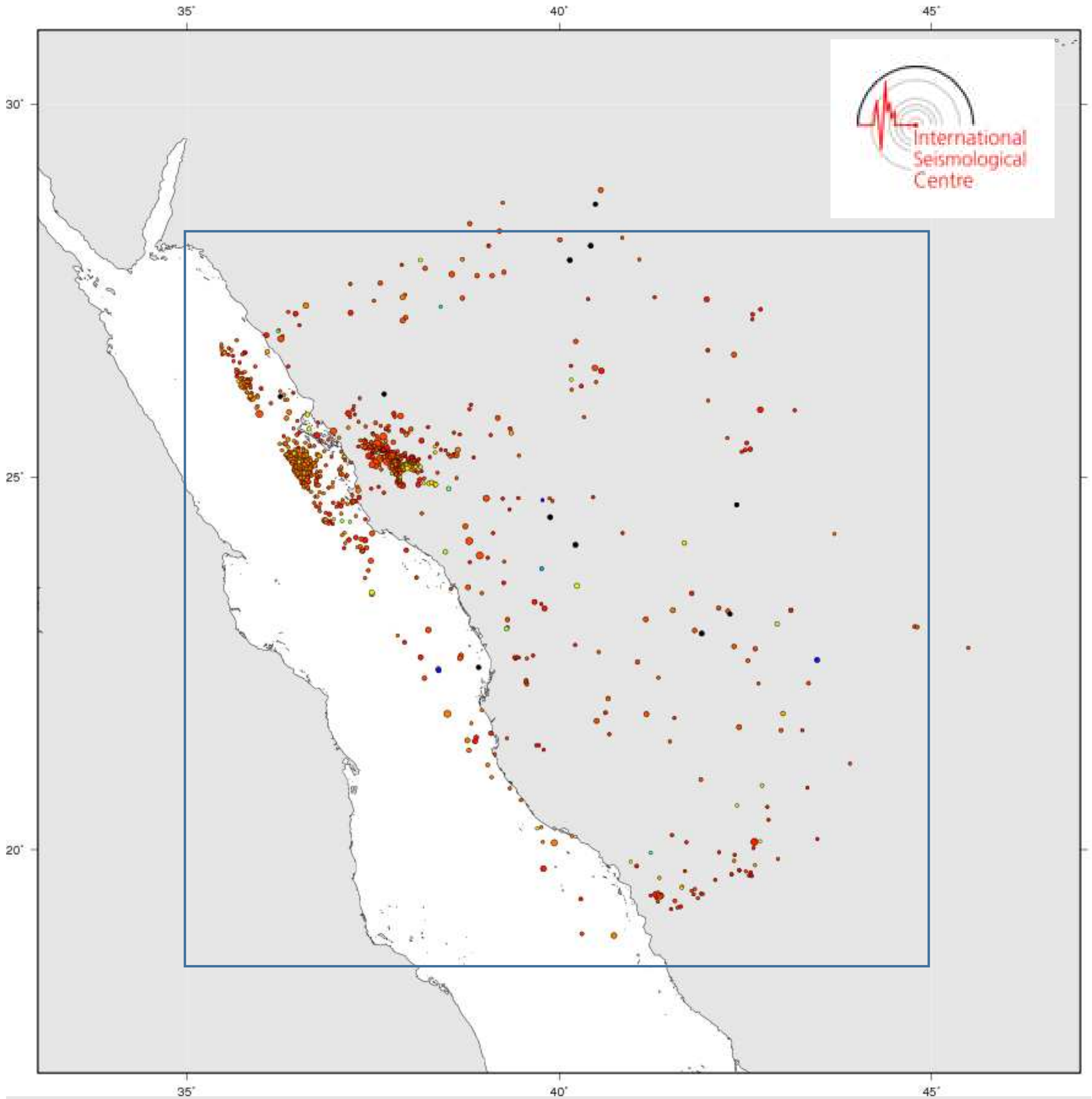


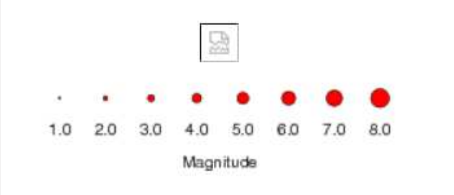
https://www.researchgate.net/profile/Abdul_Wahed_Mohamad_Khir/publication/225405387/figure/fig1/AS:302561811812352@1449147765071/Fig-1-Regional-tectonic-map-of-the-northern-Arabian-Plate-and-surrounding-regions.png

Geodetic constraints on present-day motion of the Arabian Plate: Implications for Red Sea and Gulf of Aden rifting

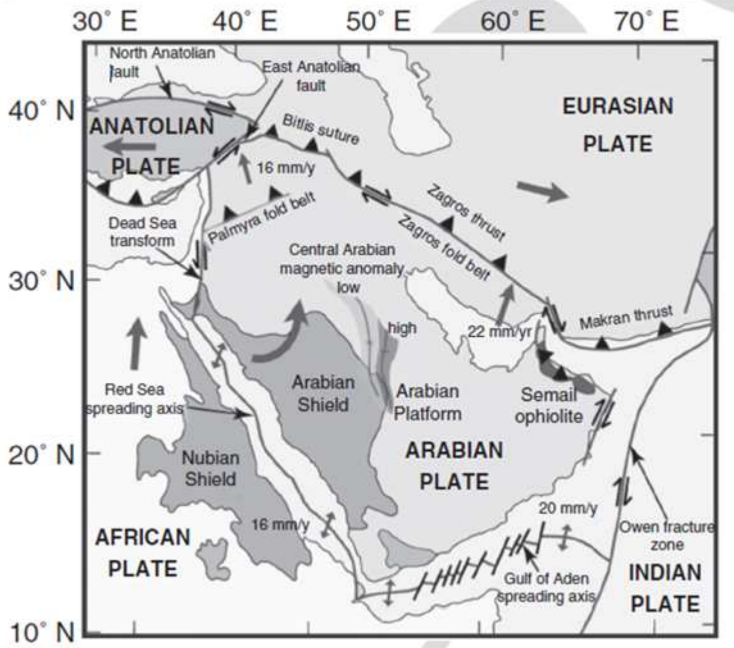


Geodetic constraints on present-day motion of the Arabian Plate: Implications for Red Sea and Gulf of Aden rifting, Volume: 29, Issue: 3, First published: 24 June 2010, DOI: (10.1029/2009TC002482)





Earthquakes



Al-Bassam, Zaidi and Husseini, 2013

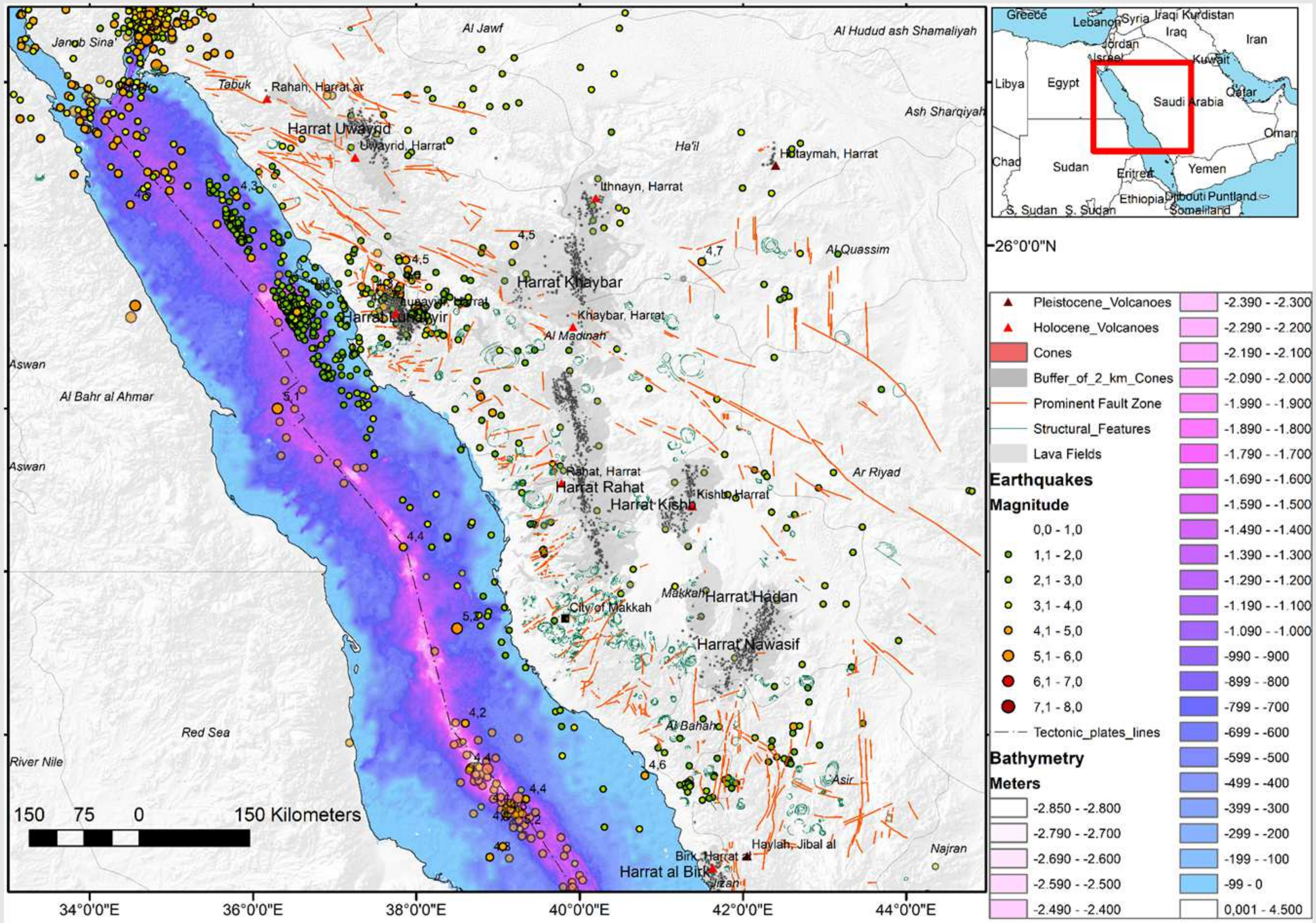
The Late Cenozoic evolution of Saudi Arabia was mainly controlled by:

- extensional processes in the Red Sea Basin,
- continental collision between Arabia and Eurasia and to the
- the left lateral strike-slip boundary to the northwest represented by the Dead Sea Transform Fault System.

International Seismological Centre, *On-line Bulletin*, http://www.isc.ac.uk, Internatl. Seismol. Cent., Thatcham, United Kingdom, 2016.

Earthquakes in West-Saudi Arabia during the last Decades

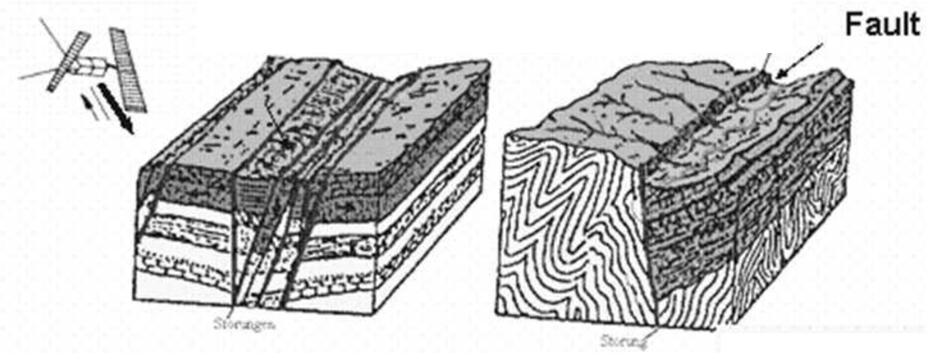
Sources: Earthquake data: USGS, ISC, EMSC, lava shapefile from USGS, Pleistocene and Holocene volcano shapefiles from Smithsonian Institution's Global Volcanism Program (GVP), cinder cones and larger lineaments (red lines) mapped based on satellite data)



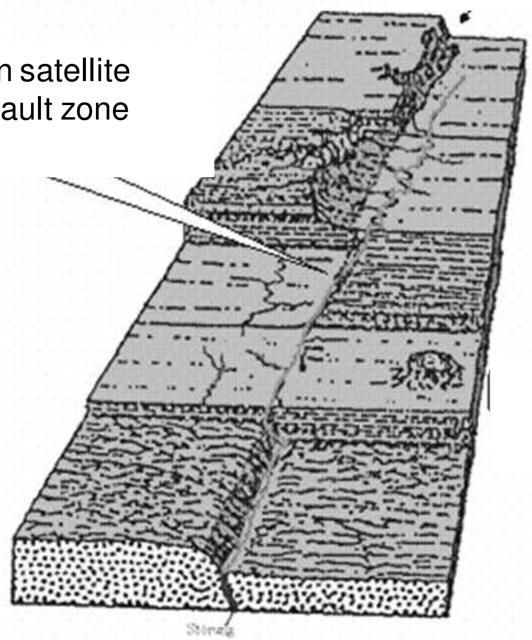
Structural / Tectonic Evaluation of Satellite Data - Lineament Analysis

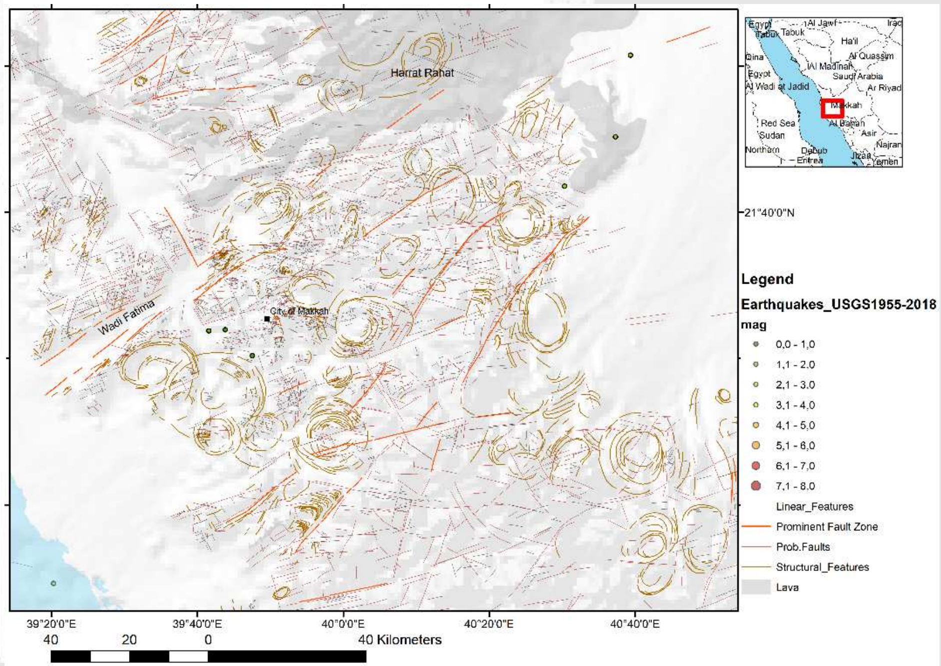
Special attention is focused on the mapping of structural features visible on satellite imageries in order to investigate the tectonic setting and to detect surface traces of fracture and fault zones.

Linear features visible on remote sensing data are mapped as lineaments (neutral term for linear features), probable fault zones and structural features.



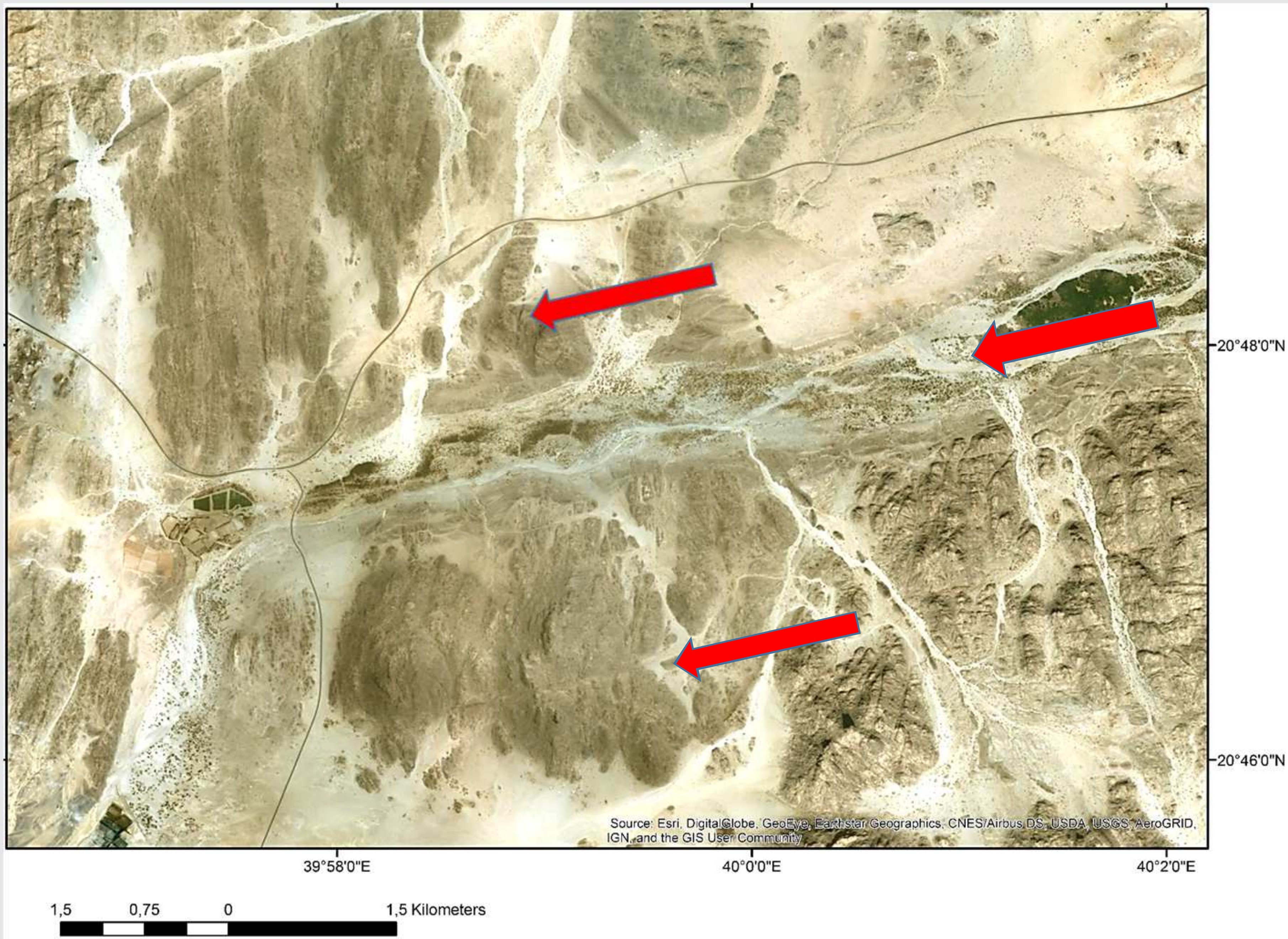
High resolution satellite imageries for fault zone detection



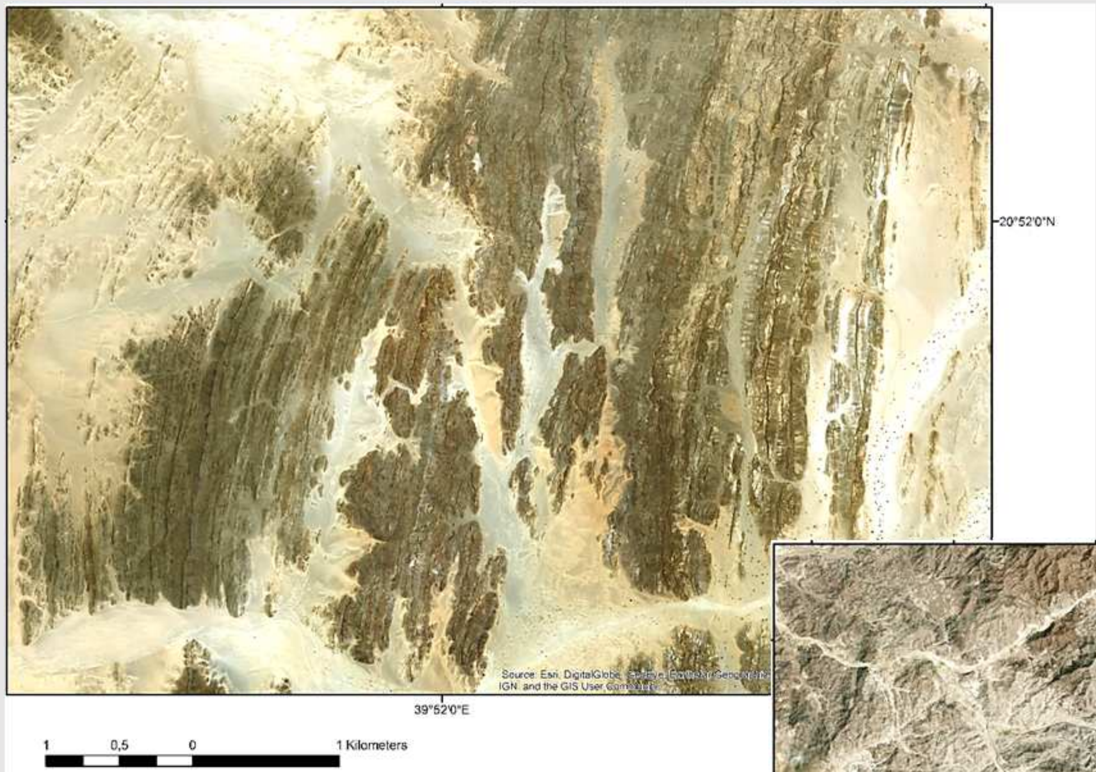


Linear features visible on remote sensing - data from the test area are mapped as lineaments and risk areas are delineated using ArcView -/ ArcGIS- Geographic Information System (GIS) –technology

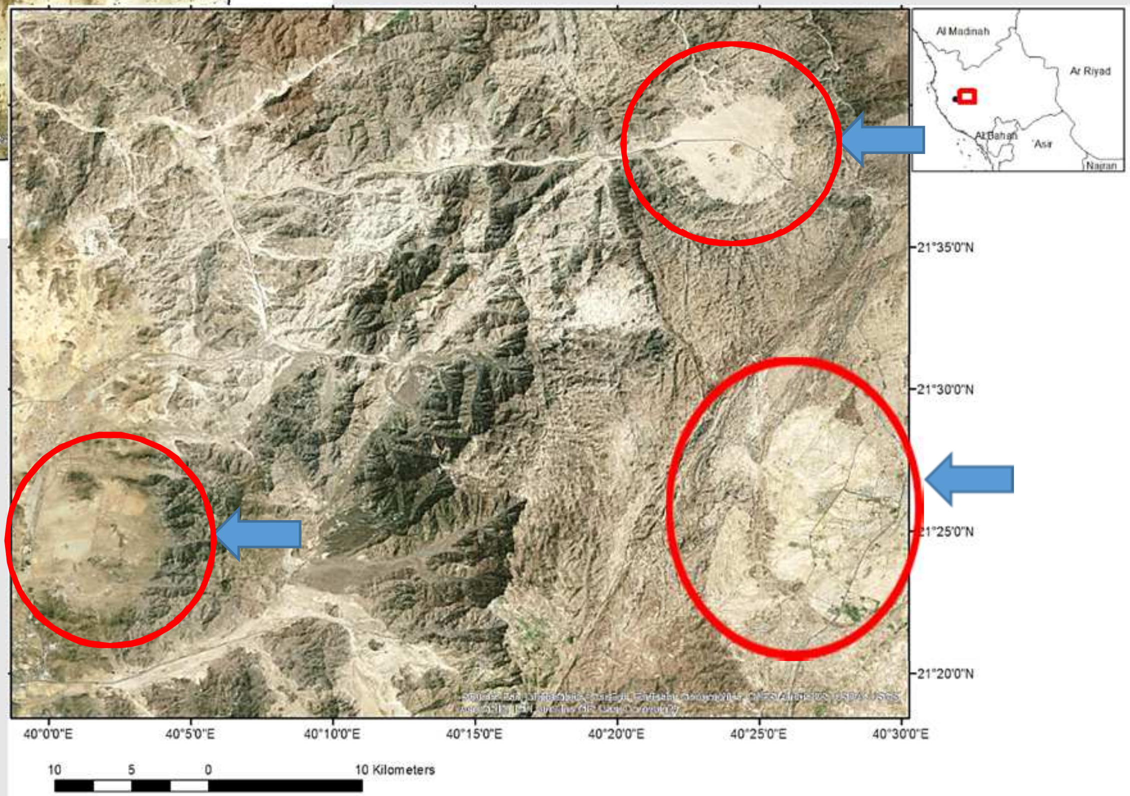
Mapping of Probable Fault Zones



Structural Features in the Rocks of the Area of the City of Makkah



Circular structures



Structural / Tectonic Evaluation of Satellite Data

The GIS integrated, structural evaluation of remote sensing data contributes to the detection of a) larger, prominent fault zones, of (b) traces of structural features such as ring structures or folds and(c) of traces of compression at the border zones of the Red Sea due to the rifting processes.

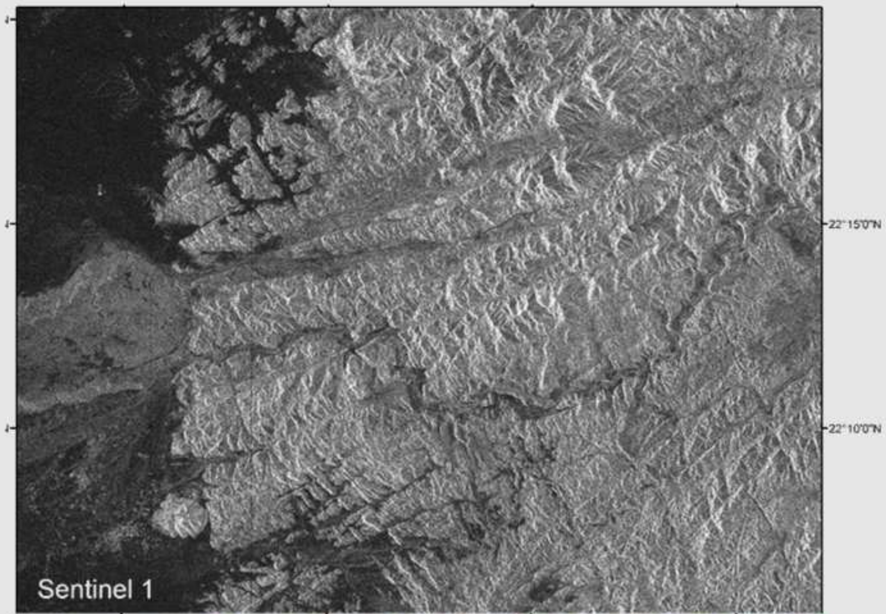
(a) The structural / geologic evaluation of optical satellite images and of radar data allows a quite precise mapping of larger **fault zones**. Existing fault zones not only play an important role for ongoing tectonic processes, but also for uprising magma. They form zones of weakness that can form an entrance for the intrusion of magmatic bodies. Whereas the oldest Precambrian / Cambrian rocks show evidence of many stress imprints in the scope of earth geologic history, the youngest strata provide hints of the more actual geodynamic processes. Whenever distinct linear traces of fault zones and shear zones (such as scarps and valleys cutting through older lithologic units) are visible on the satellite images, there is a hint related to active faults. The Principal Component analysis (PCA) of Landsat data helps to identify larger, prominent fault zones.

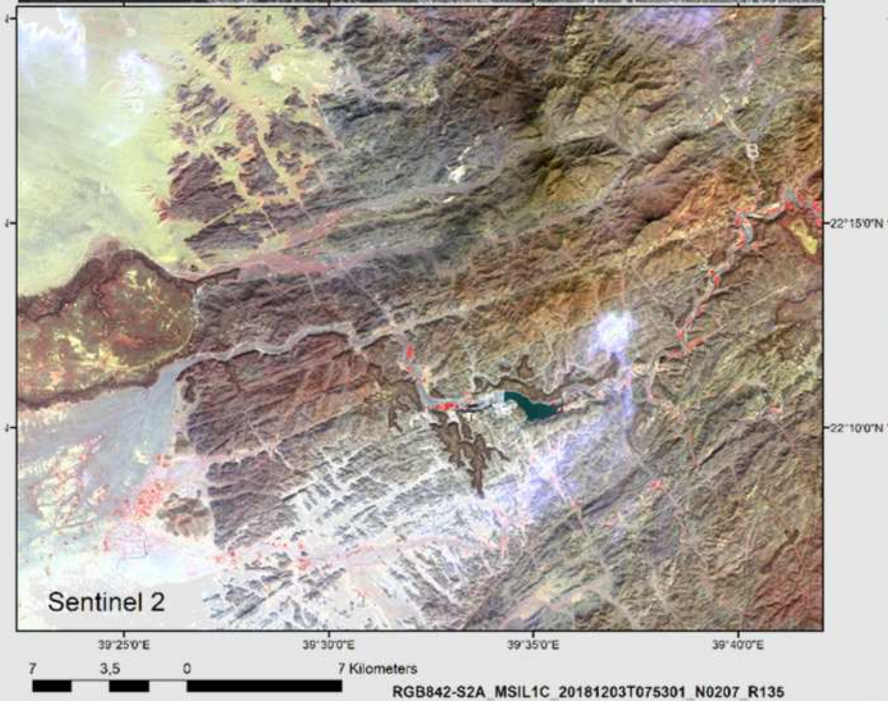
(b) Another important aspect is the detection of **circular structures** in the Precambrian and Cambrian rocks, even when deeply eroded and only visible on the satellite images because of the circular outline. The annular structures show circular or oval shapes and they are different, in their structures, from other surrounding geologic phenomena, most of them consisting of intrusive batholiths. Also, these structures differ in their dimensions, origin and the characteristics of their identification on satellite images. Some form prominent domes, others are only visible due to circular, tonal anomalies in the sedimentary covers. Their dimensions range from many meters till hundreds of meters up to more than 100 kms. The majority of these circular structures with 10 to 25 km in diameter were generally created by Precambrian intrusive, magmatic bodies of different composition (mainly granitc) and geomechanic properties.

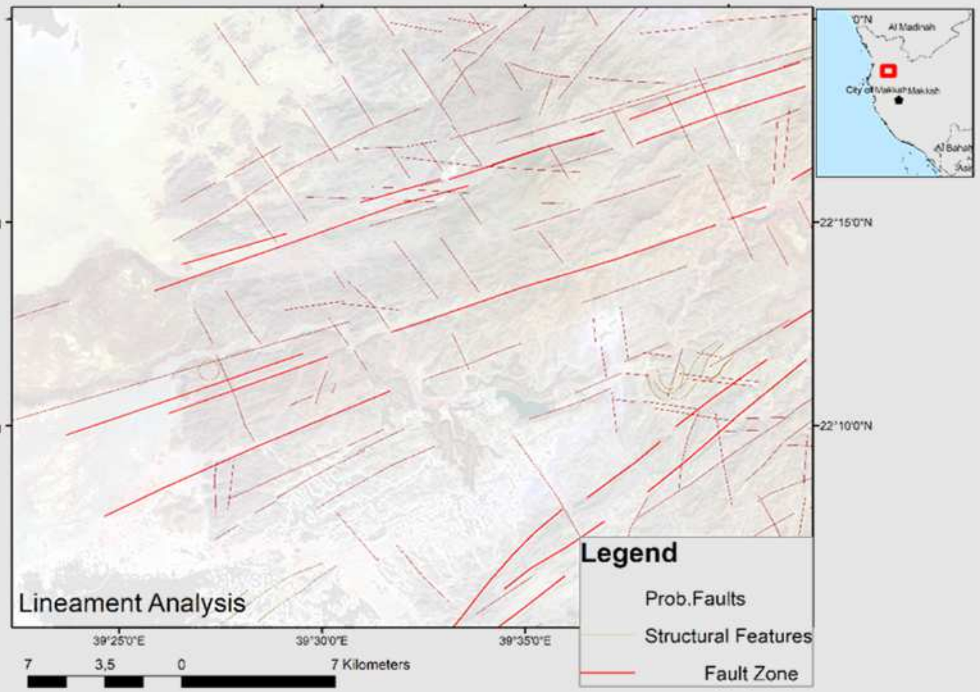
The knowledge of the position of circular structures plays an important role when dealing with seismic and aseismic movements in this area. The earthquake pattern might be influenced by the circular structures as well as the recent volcanic activity. It seems as if the larger fault zones are “bending” around the structures. For a better understanding of the geomechanic processes in this area (movements towards northeast with velocities of 10 to 15 mm / year, it has to be considered that the intrusive bodies might react mechanically different than the surrounding rocks, potentially forming asperities that could lead to earthquakes in case of stress accumulation. Ring structures with their different, geomechanical properties, especially when occurring block-wise, form a relatively stable “hindrance” against tectonic movements.

Traces of compression visible on Sentinel 1 radar and Sentinel 2 optical images as NW-SE oriented parallel, linear features

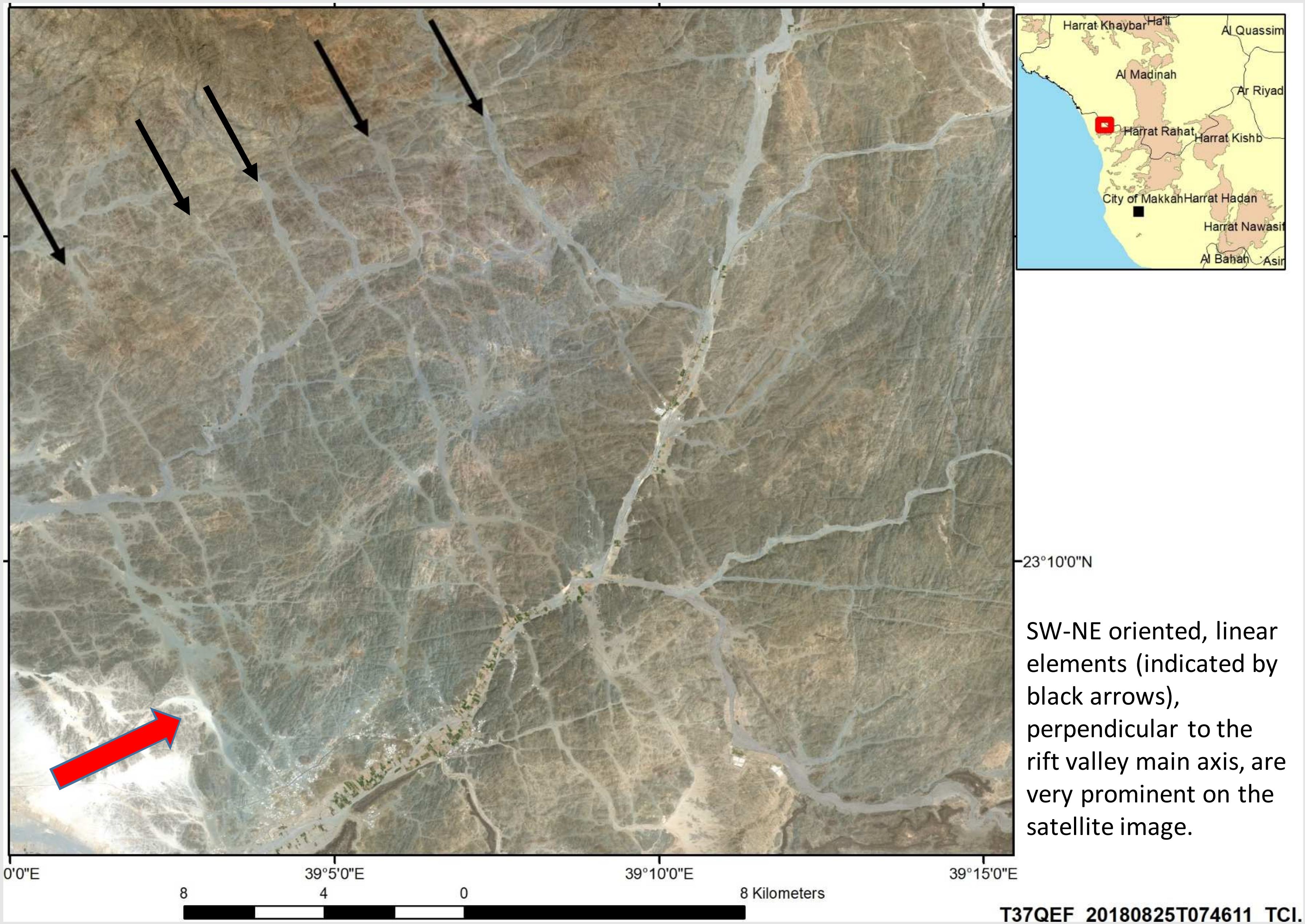
The coast-near areas clearly show evidence of linear features oriented NW-SE to NNW-SSE parallel to the axis of the Red Sea rift valley. As the area is moving towards NE, theses curvi-linear features might be related to traces of compression due to accretionary thrusting and thrust-related structures. The striking direction of the assumed traces of compression changes in close relation, parallel to the orientation of the rifting axis from NW-SE to NNW-SSE. SW-NE oriented, linear elements, perpendicular to the rift valley main axis, are very prominent on the satellite images as well. Of course, there is a need to verify these features in the field. These linear features could be partly correlated with known larger shear zones such as the Wadi Fatima shear zone





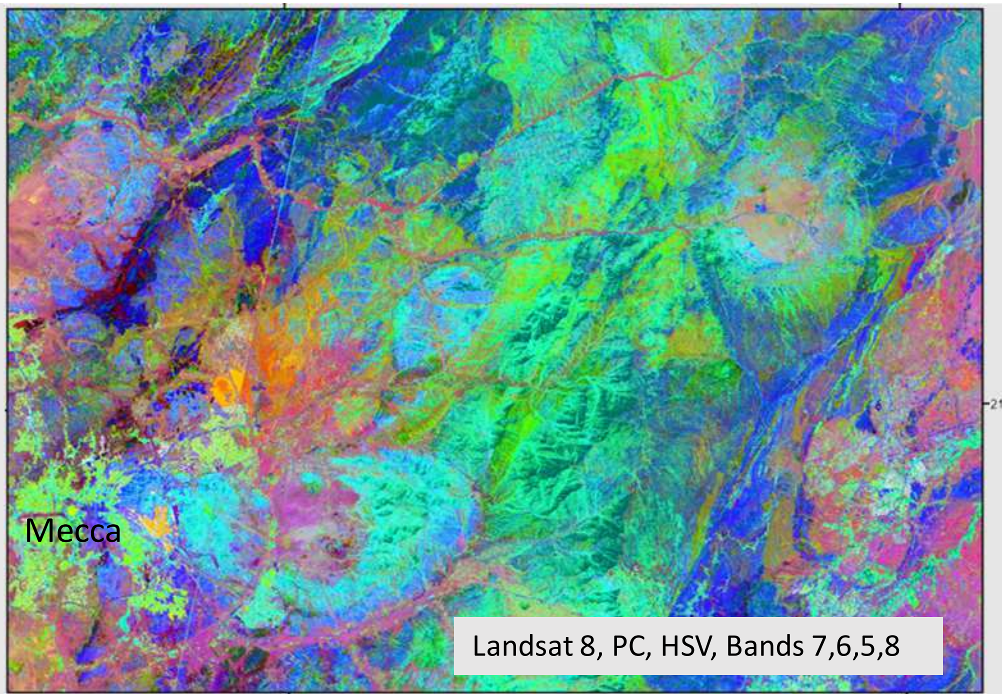


Traces of Compression visible on a Sentinel 2 Scene

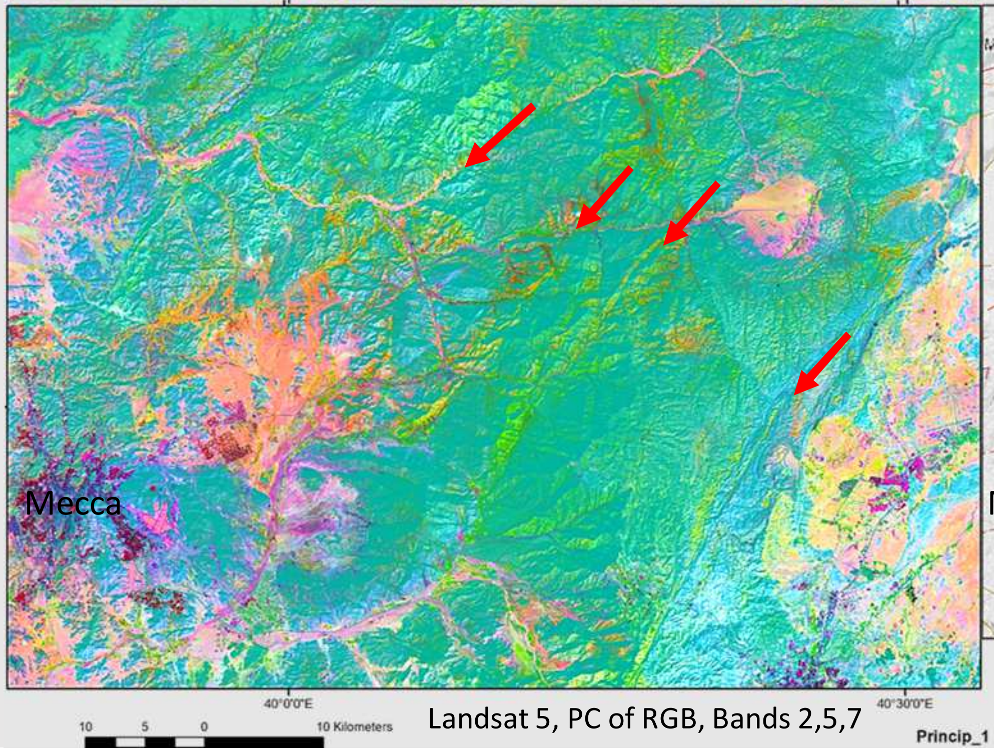


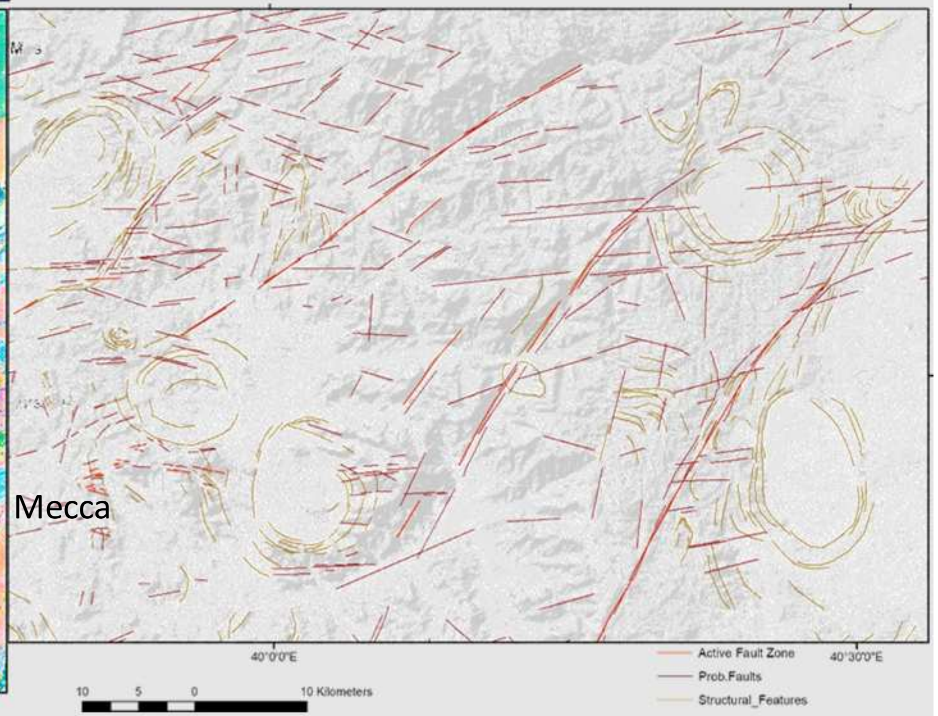
SW-NE oriented, linear elements (indicated by black arrows), perpendicular to the rift valley main axis, are very prominent on the satellite image.

Detection of Traces of Active Fault and Shear Zones on Landsat-Principal Component Images ?

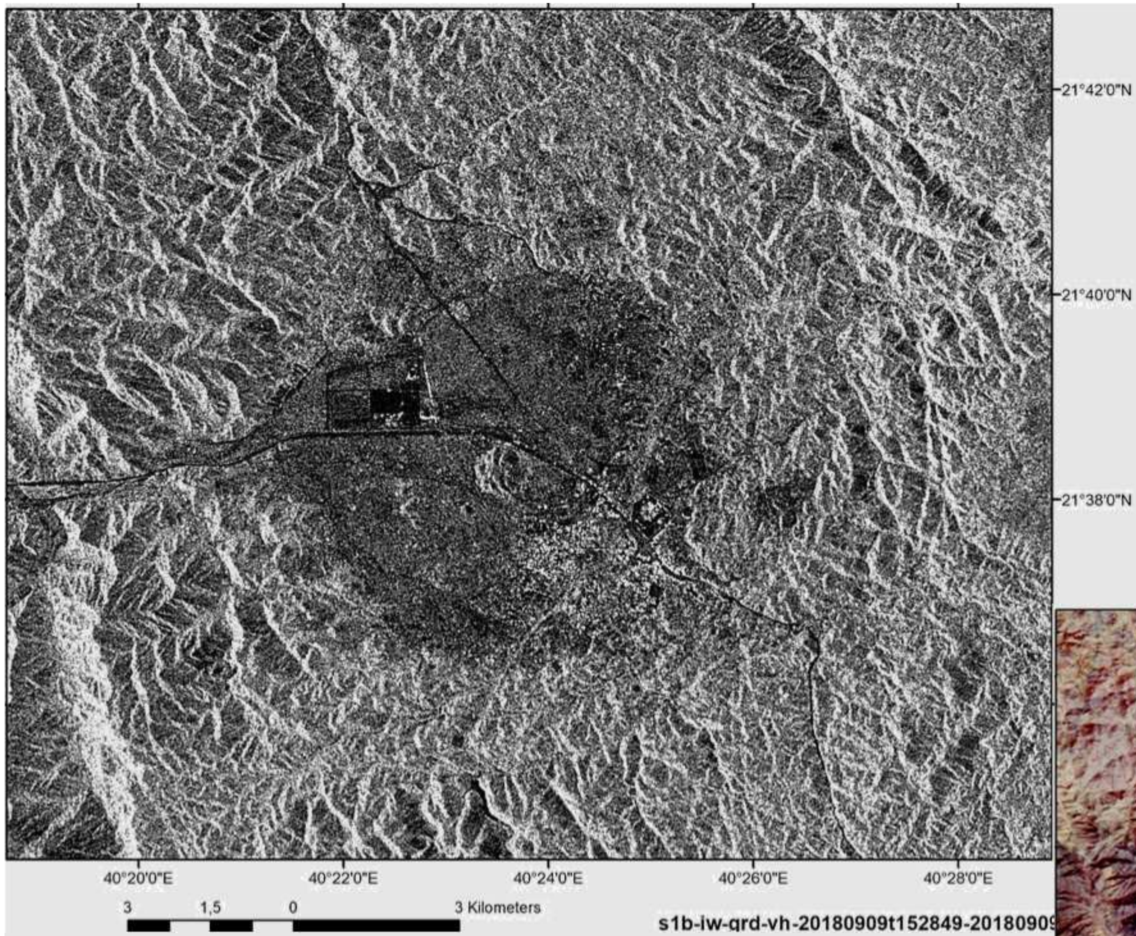


Linear features tracing subsurface structures



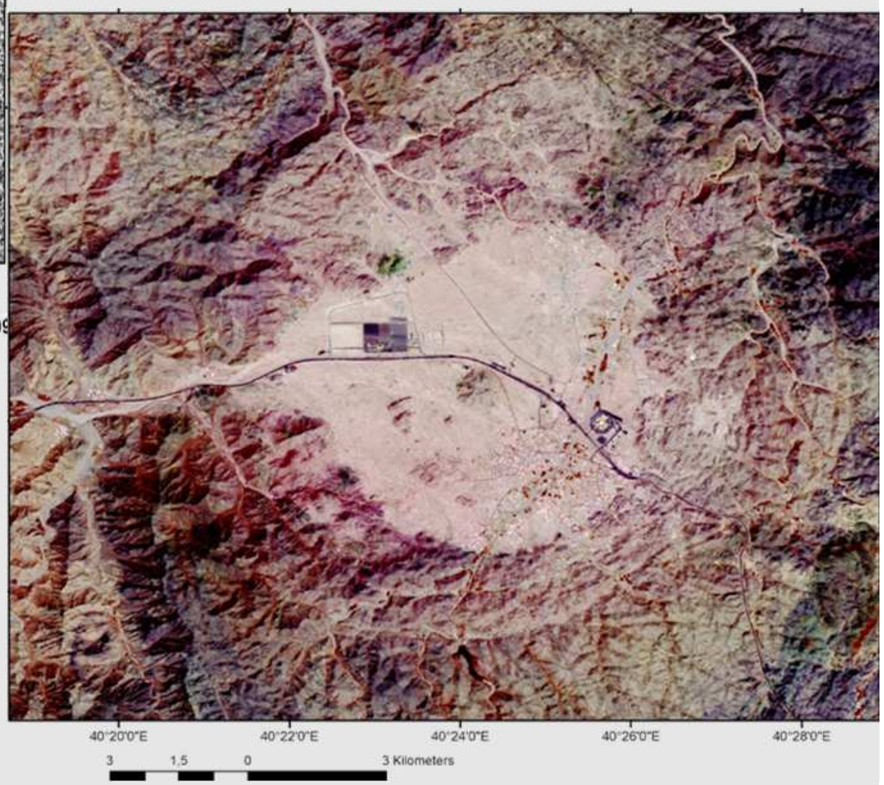


Mapping Circular Structures

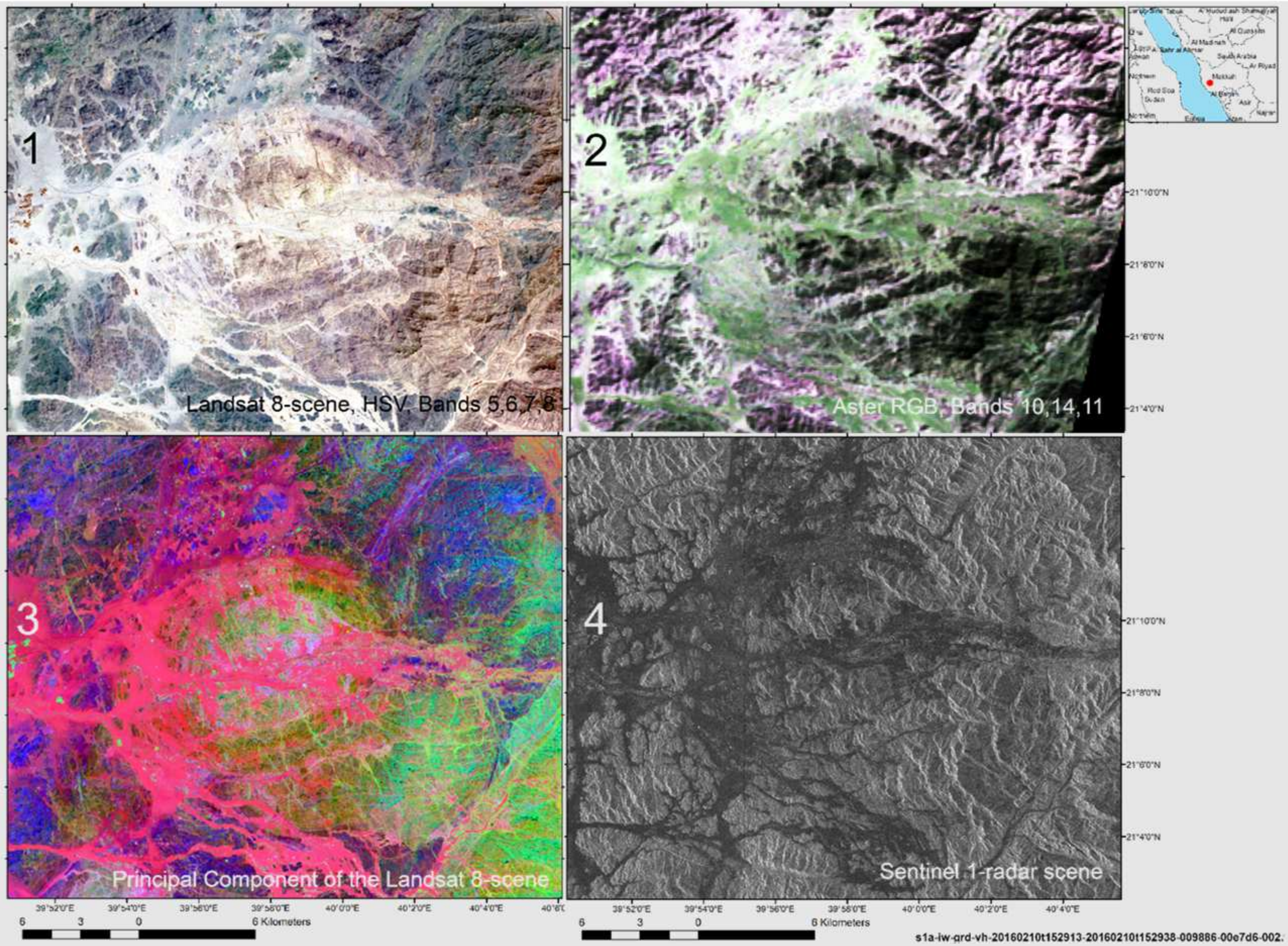


Sentinel 1-radar scene enhancing the visibility of the structural pattern

Most of the ring structures in the Precambrian rocks are related to magmatic bodies.



Landsat 8-scene



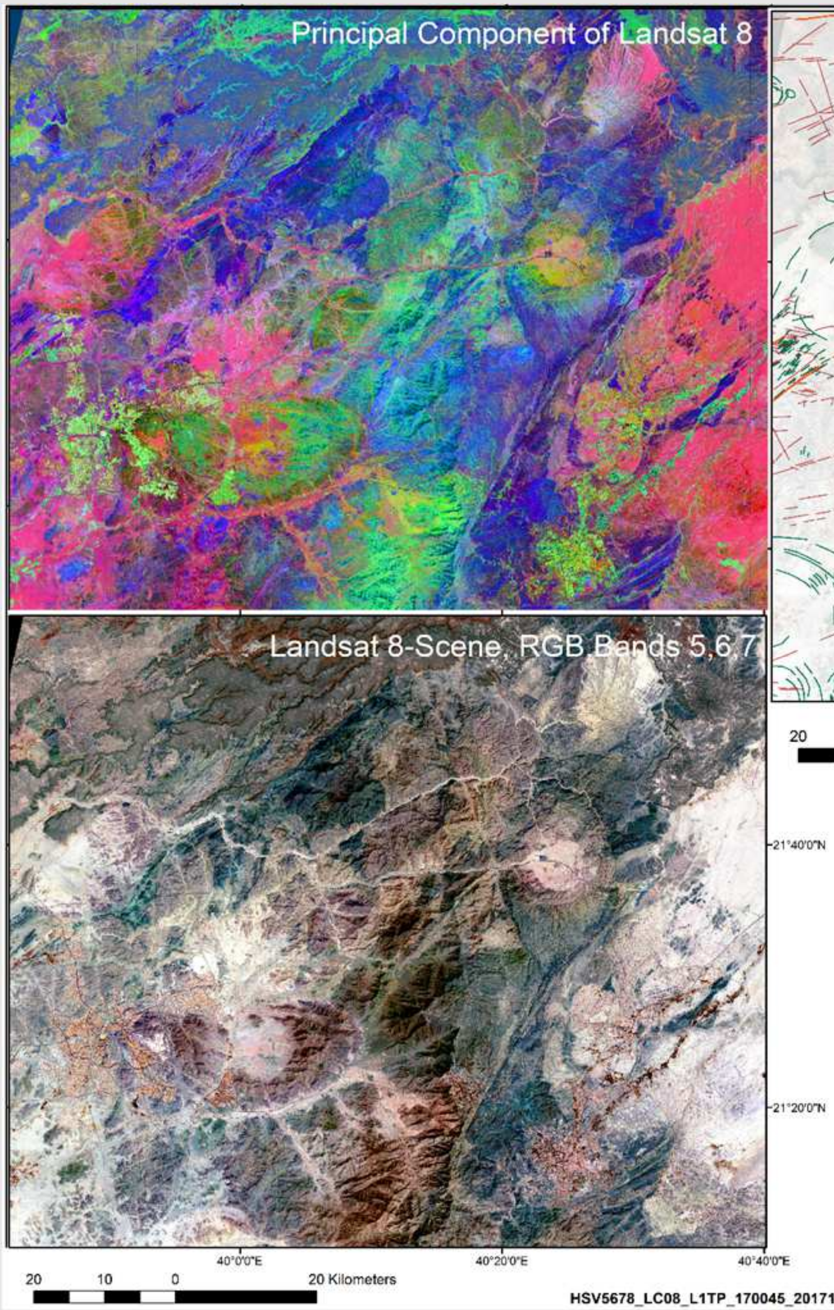
Use of different satellite data for providing structural information of a circular structure in the south of Makkah

1 - Landsat 8, HSV, Bands 5,6,7,8_LC08_L1TP_170045_20171007_20171023_01_T1

2 - ASTER, RGB, Bands 10,14,11-AST_L1T_00301032018080650_20180104121027_17567

3 – Principal Component (PC) of the Landsat 8-data

4 – Sentinel 1-radar image, s1a-iw-grd-vh-20160210t152913-20160210t152938-009886-00e7d6-002



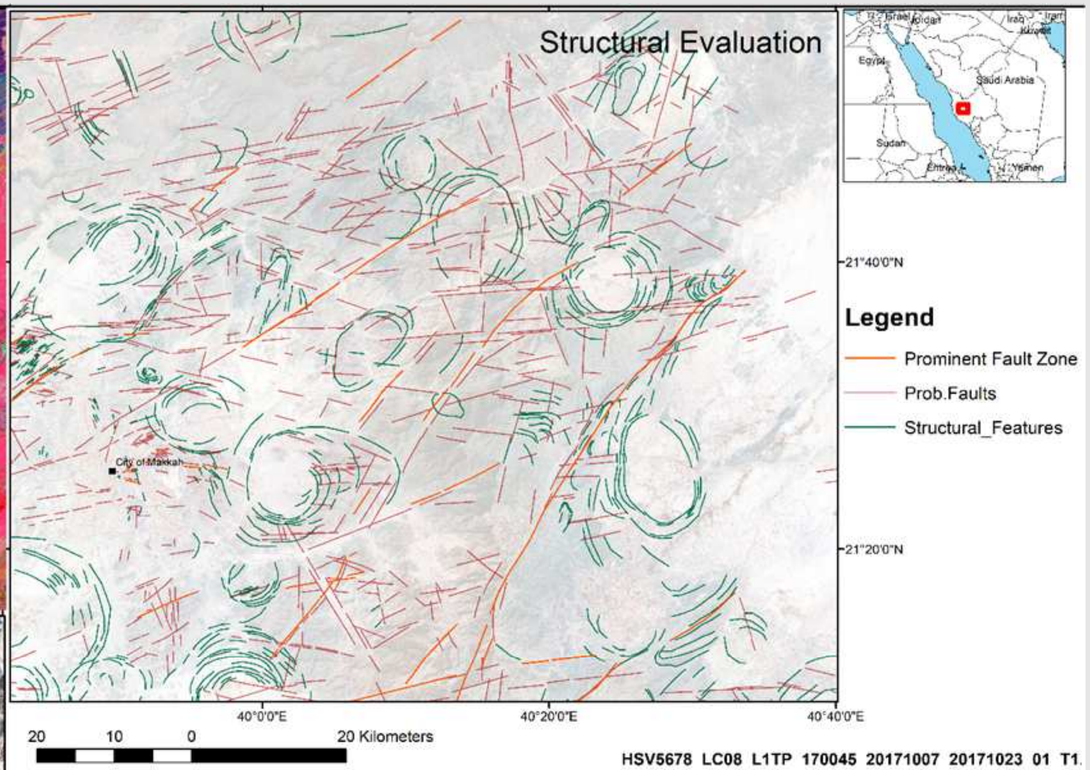
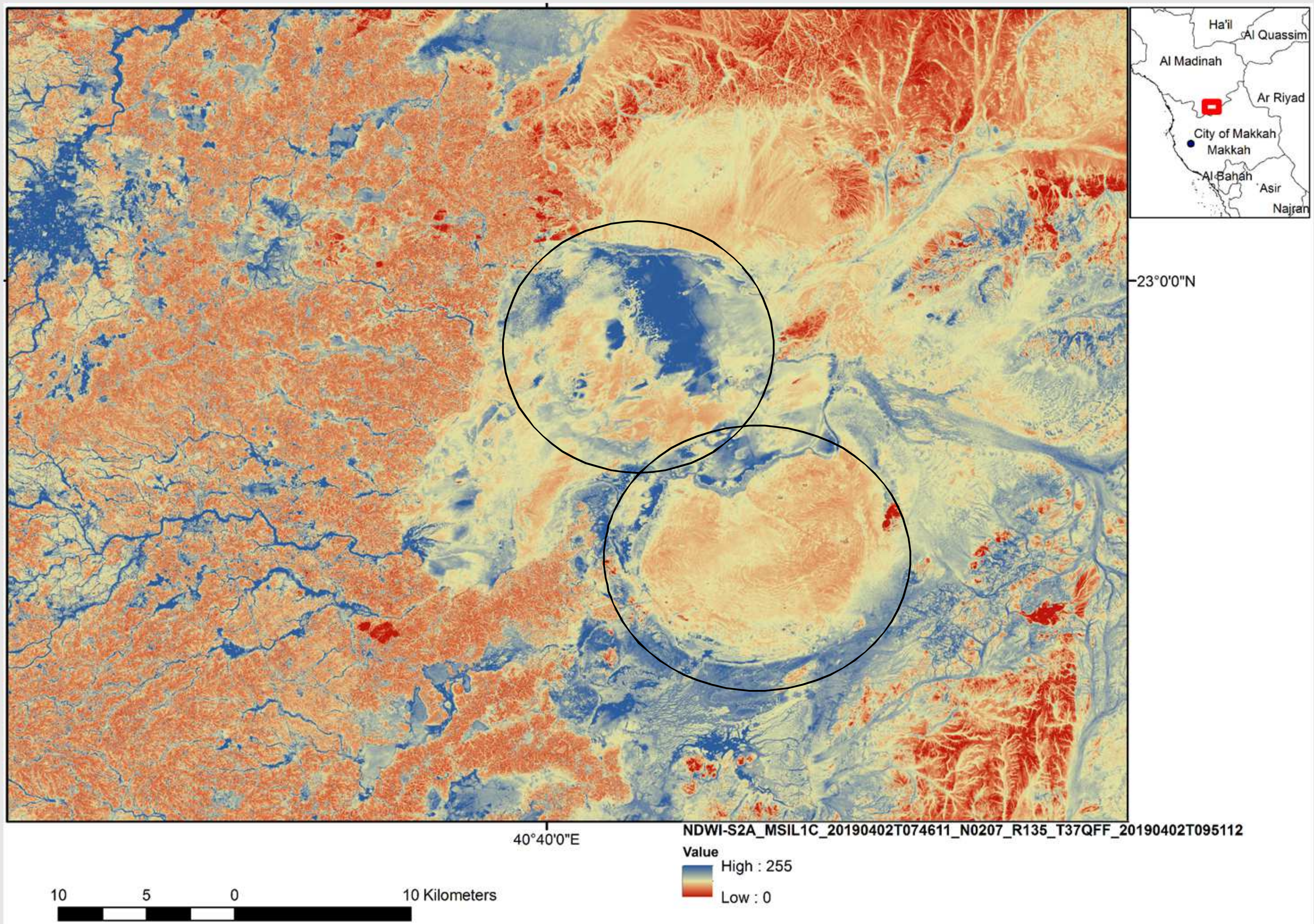


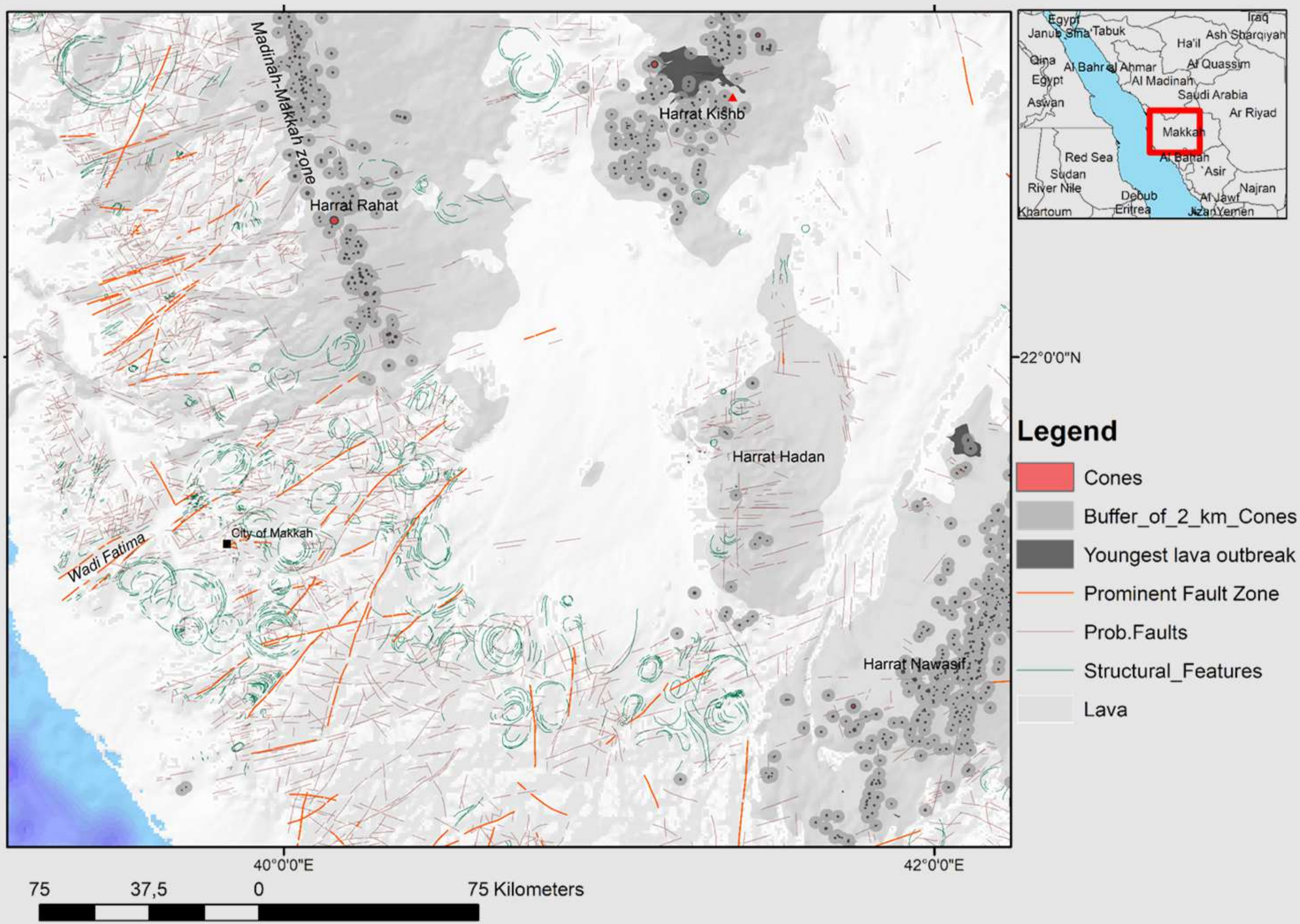
Image processing and structural evaluation for the detection of prominent fault zones and circular features

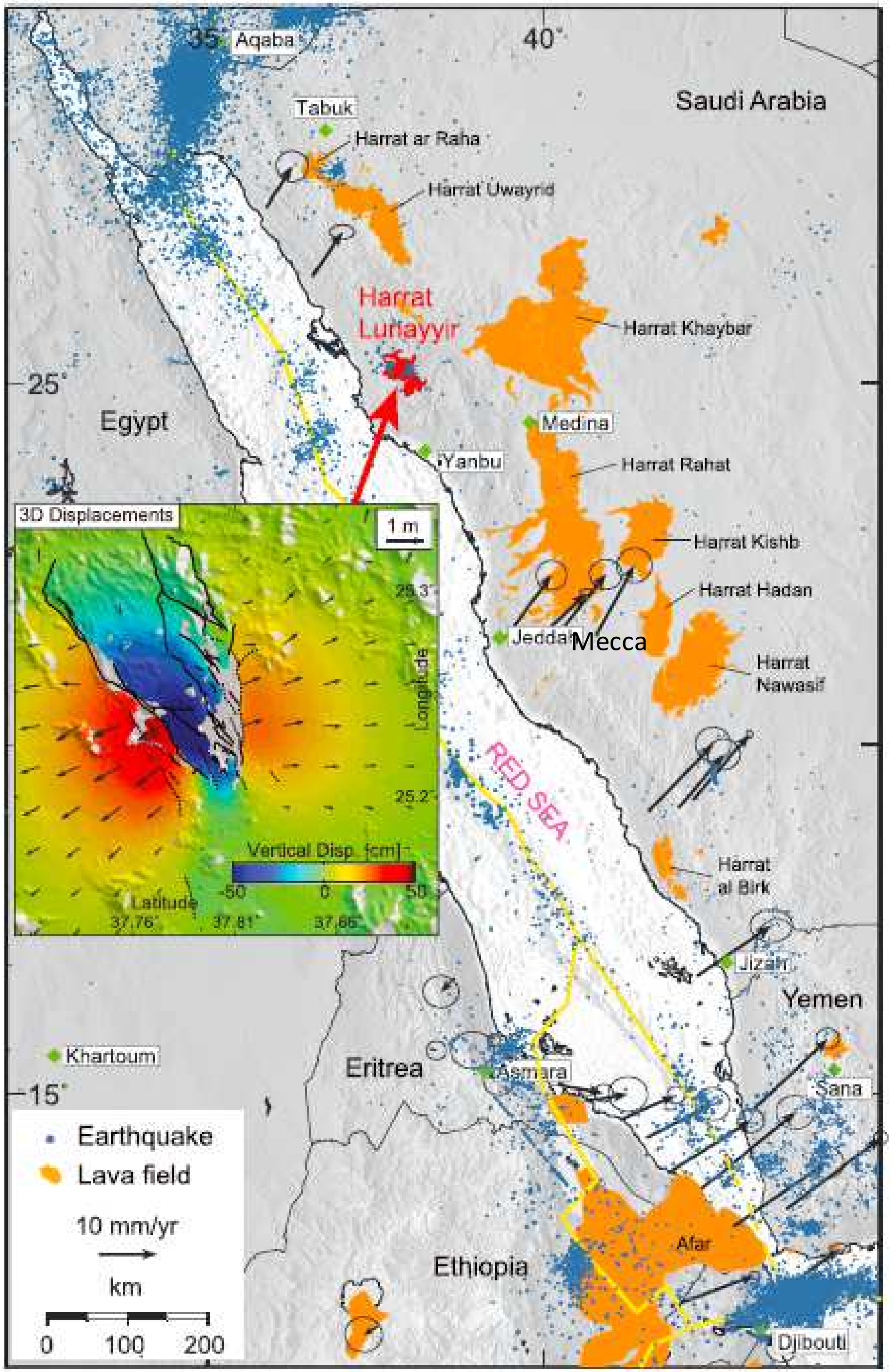
PCA is a linear transformation that reorganizes the variance in a multiband image into a new set of image bands. These PC bands are uncorrelated linear combinations of the input bands. A PC transform finds a new set of orthogonal axes with their origin at the data mean, and it rotates them so the data variance is maximized (ESRI Online Help in ArcGIS)

Ringstructures visible on a Sentinel 2-NDWI Water Index Scene



Larger, prominent lineaments, ring structures and volcanic features mapped based on different satellite data





Volcanic Activity

Main Cenozoic lava fields in Saudi Arabia

Although most harrats are inactive, the volcanic lava field of Harrat Rahat between Makkah and Al Madinah has experienced volcanism in historic times. The oldest lavas near Madinah are only about 2 million years old, and the youngest lavas (less than 6000 years old) resulted from 11 eruptions, with 2 historic eruptions in AD 641 and AD 1256. The 641 AD eruption resulted in a small line of cinder cones to the southwest of the city (Saudi Geol.Survey).

Xu, W., S. Jónsson, F. Corbi, and E. Rivalta (2016), Graben formation and dike arrest during the 2009 Harrat Lunayyir dike intrusion in Saudi Arabia: Insights from InSAR, stress calculations and analog experiments, J. Geophys. Res. Solid Earth, 121, doi:10.1002/2015JB012505.

Monitoring of Volcanism with Remote Sensing and GIS Tools

Identifying and monitoring of fault zones

- Helps to identify zones of weakness in the upper crust, allowing the uprise of magma (diking propagation, cone development)

Monitoring of magmatic activity

- Contributes to the understanding of earthquake swarms related to magmatic activity

Monitoring of geodynamic activity

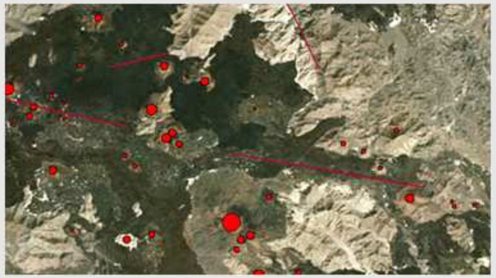
- Contibutes to the knowledge about the geodynamic / plate tectonic movements,
- to study the tectonic deformation and the magmato-tectonic interactions involved in the active rifting process using the combination of geodetic techniques, remote sensing and seismology.

Creation of a GIS integrated Data Base

When dealing with the safety of infrastructure in the Makkah area, it is of great importance to analyse the volcanic phenomena and magmatic activity, as it provides information of the geodynamic pattern.

Remote Sensing Contribution to the Detection and Mapping of Volcanic Features

- Mapping of volcanic cinder cones

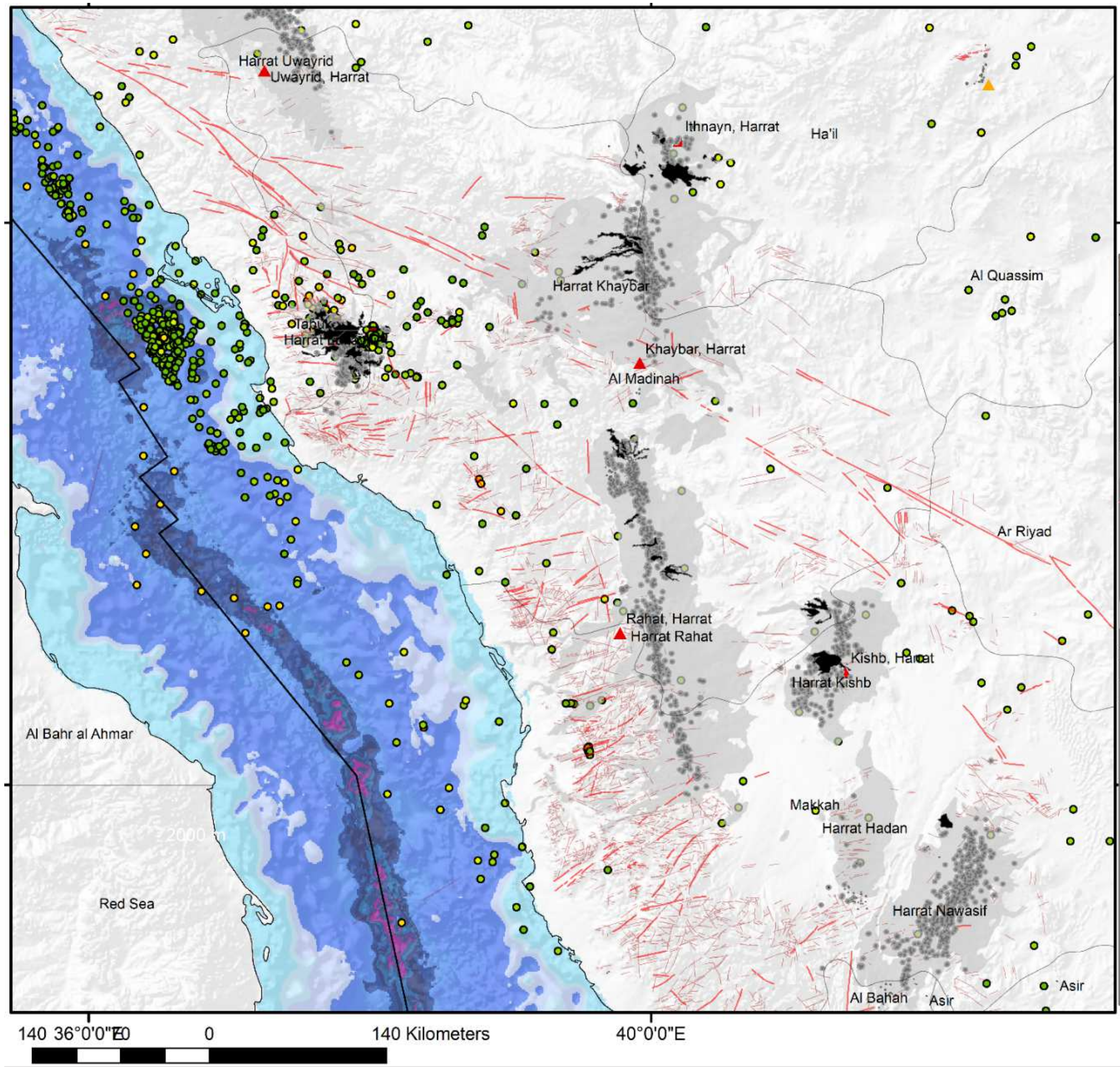


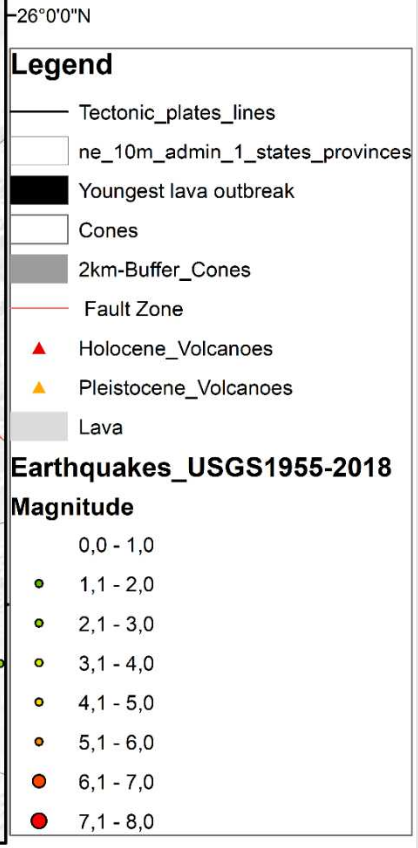
- Mapping of visible fault zones and dikes in the area of cinder cone fields

- Mapping of the most recent lava flow

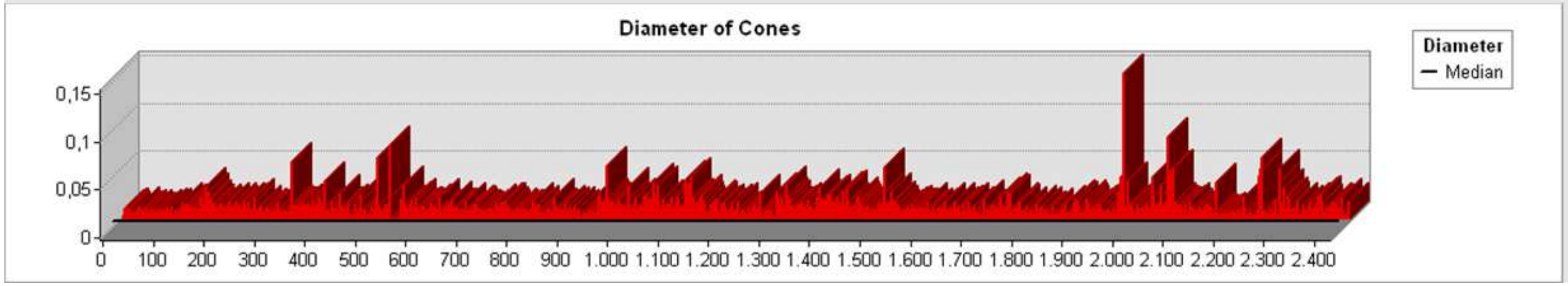
- Detection of traces of age differences and types of volcanic features based on erosional and weathering conditions and lithologic composition

Larger, prominent lineaments and volcanic features mapped based on different satellite data





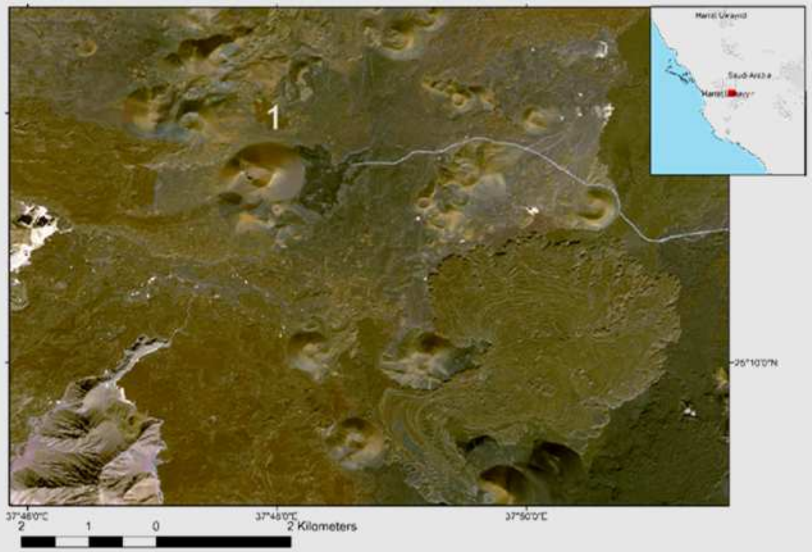
Size of cinder cones (based on about 2500 mapped cinder cones) in W-Saudi Arabia

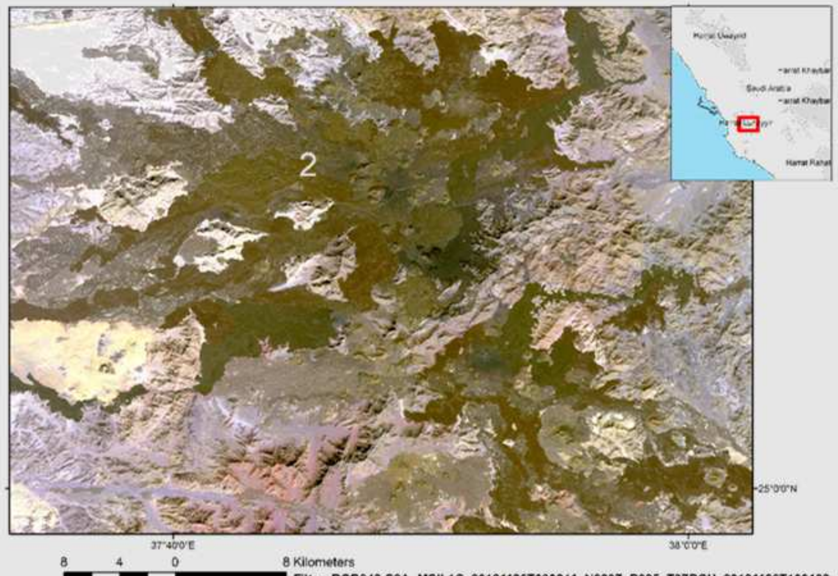


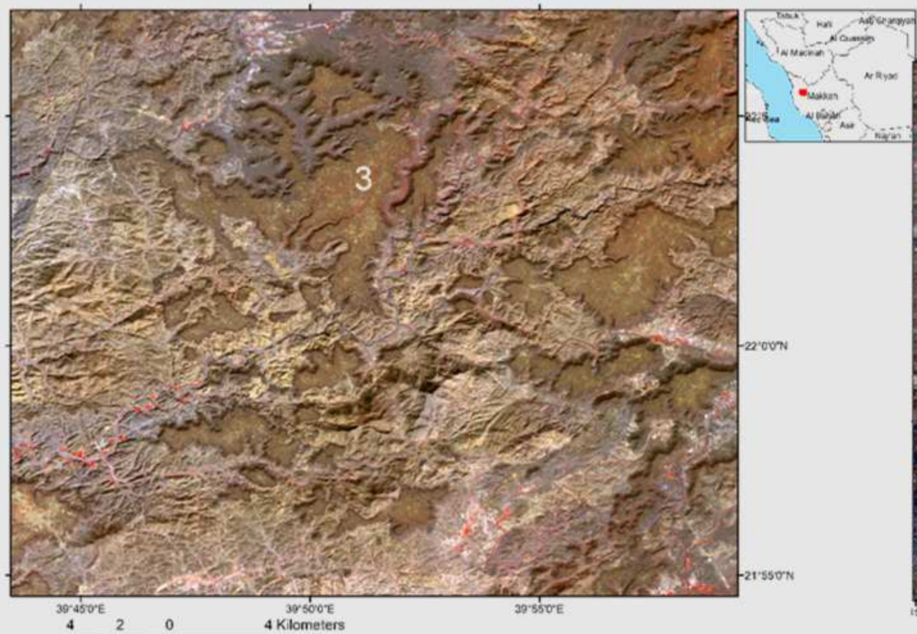
About 2500 cinder cones were digitized. The size of the cinder cones is relatively constant about 200 to more than 1000 m in diameter.

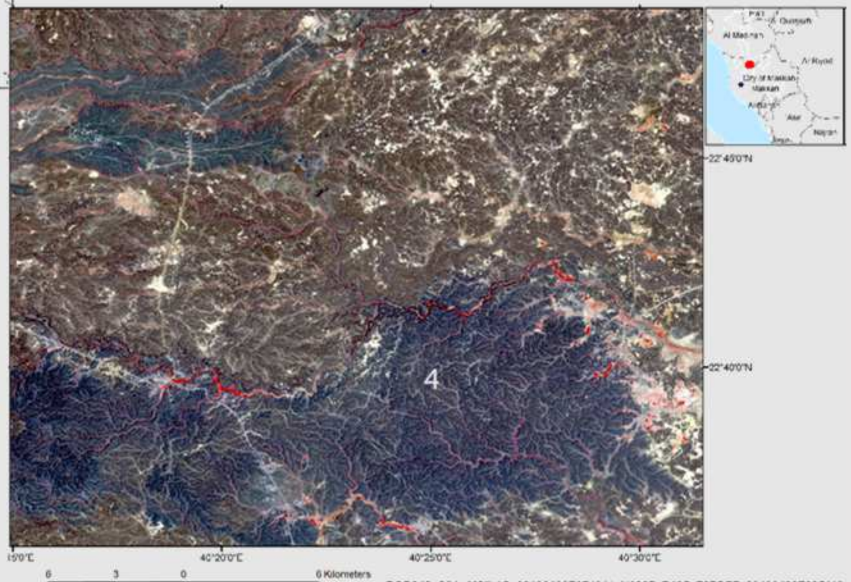
Geomorphologic types of volcanic features

1- cinder cones, 2 – lava outbreak with high lava viscosity, 3 – lava inselbergs, 4 – eroded lava sheets with drainage patterns



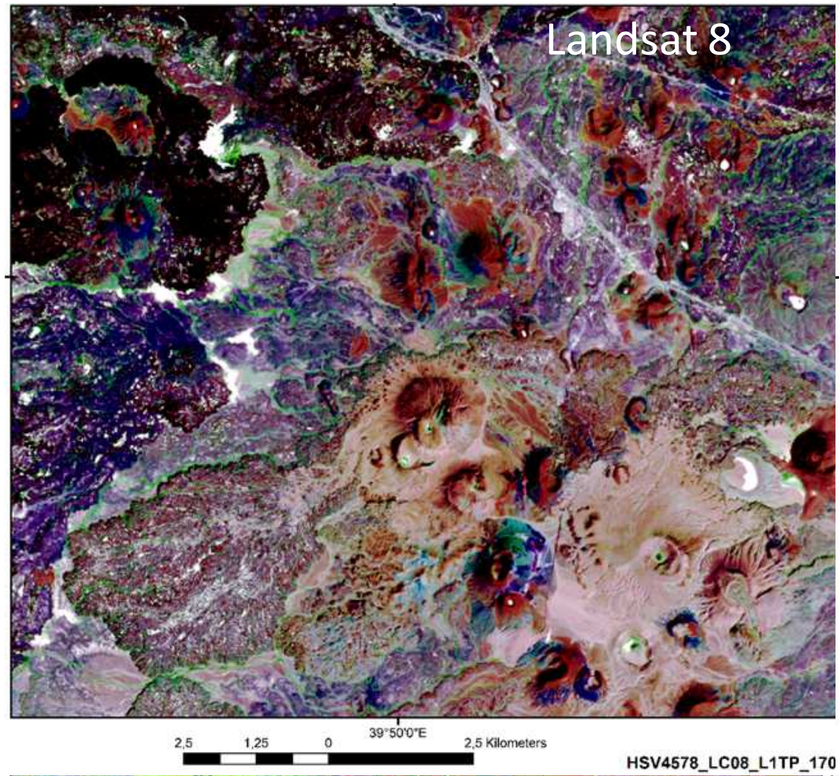


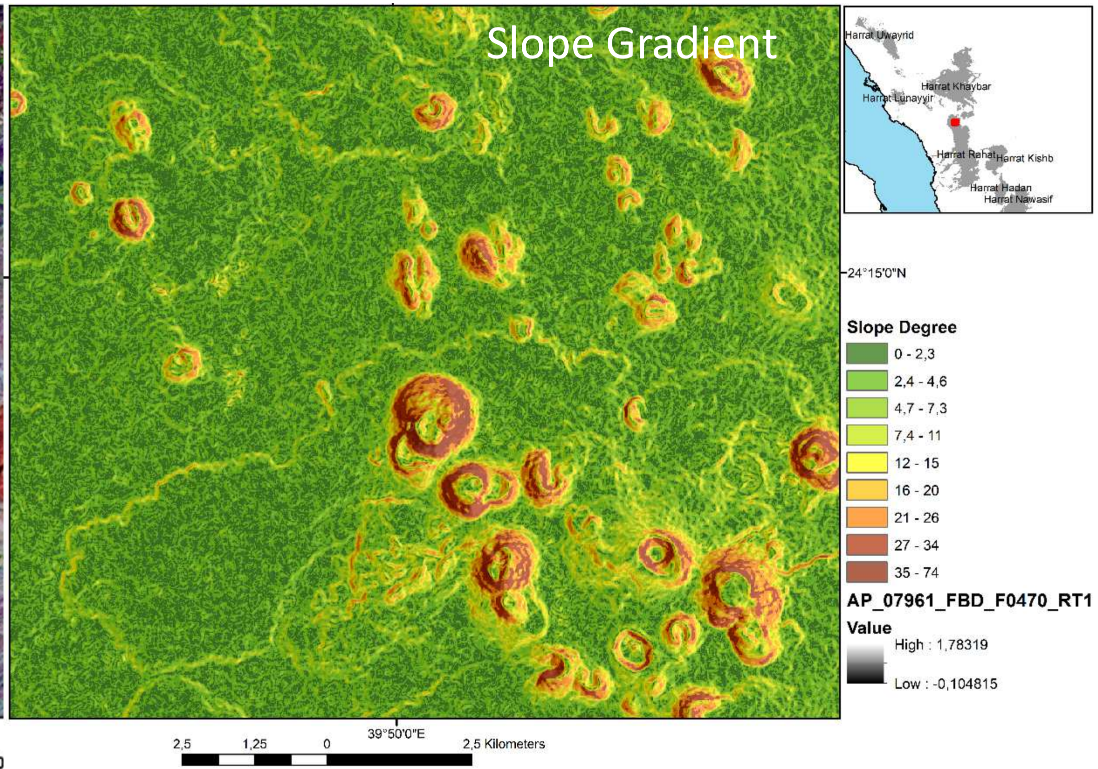


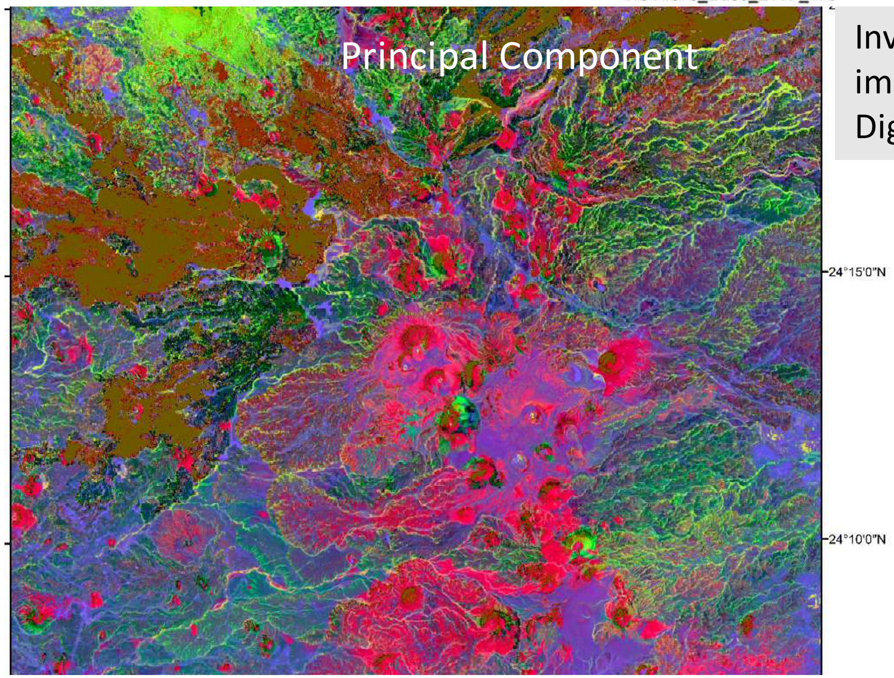


RGB842-S2B MSIL1C 20190117T075249 N0207 R135 T37QEE 20190117T0858:

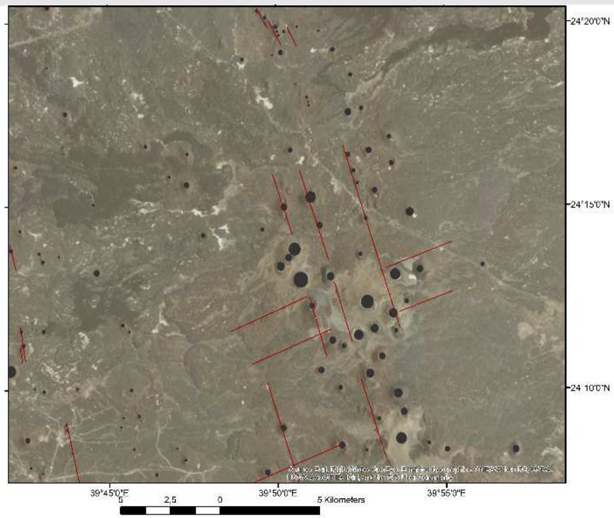
RGB842_S2A_MSIL1C_20190402T074611_N0207_R135_T37QFF_20190402T095112:



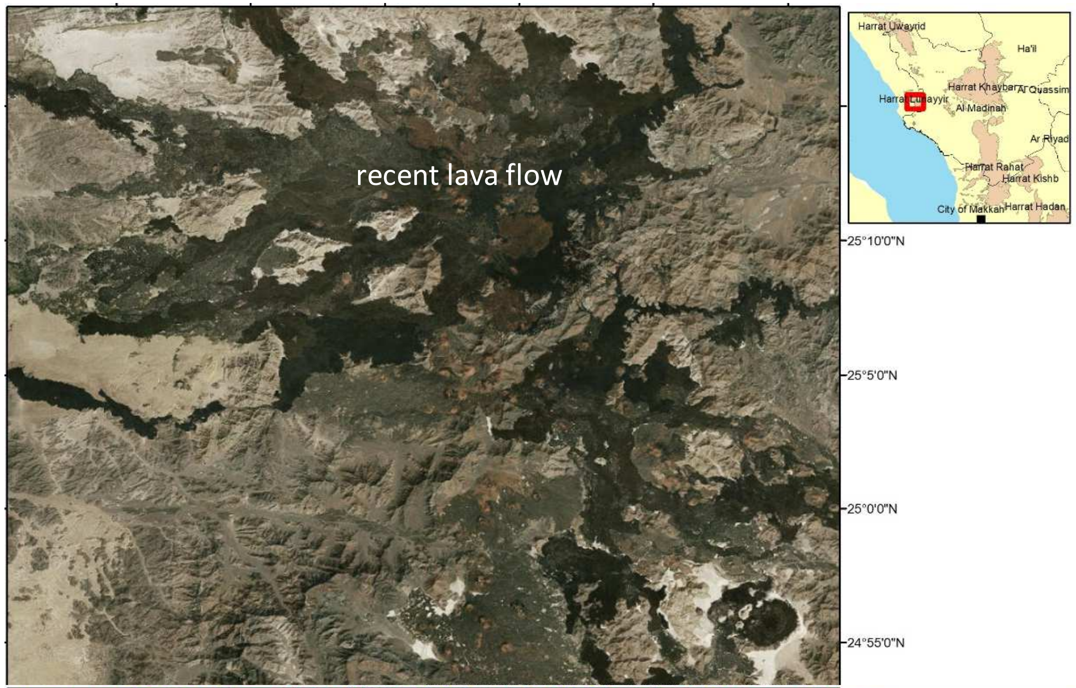


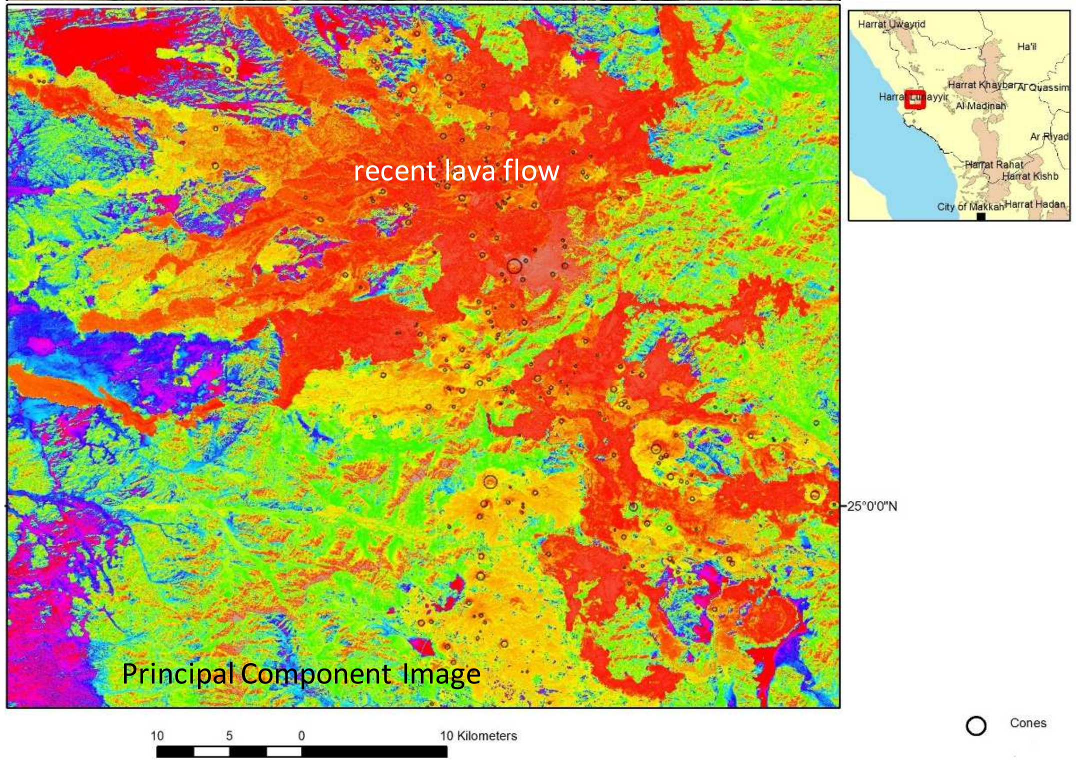


Inventory of volcanic features and their properties using digital image processing of Landsat 8 and Sentinel 2-data and ALOS PALSAR Digital Elevation Model (DEM) data



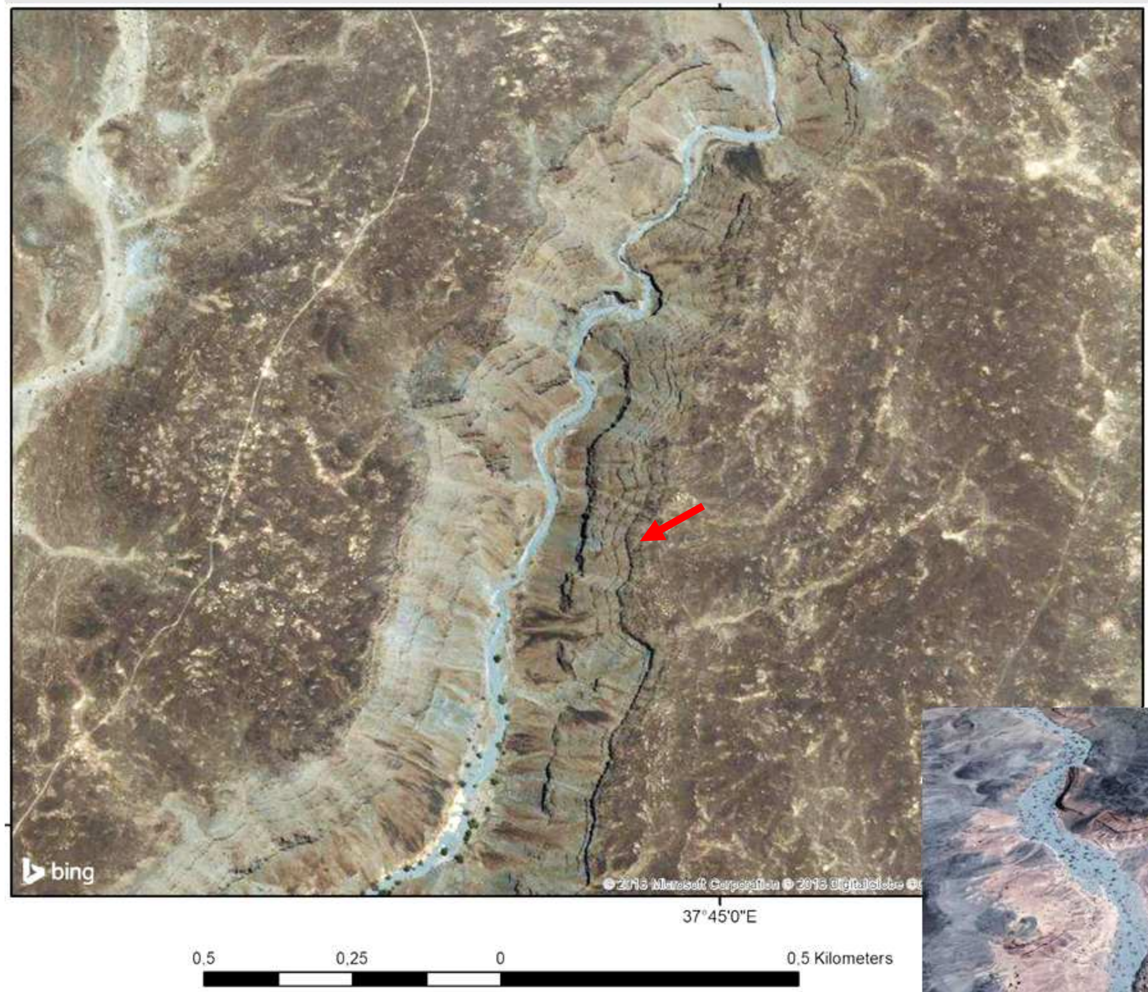
Recent Lava Flow visible on Sentinel 2 Principal Component and World Imagery Scenes





Subsidence and fissures in Harrat Lunyyir, and b fault with a length of 8 km occurred in Harrat Lunayyir, Saudi Arabia due to earthquake activity in relation to magma movements. Note: 1 fault (use white lettering o opening 45 cm, 2 fault down drop 78 cm, and 3 fault total motion 91 cm (Youssef and März, 2013)

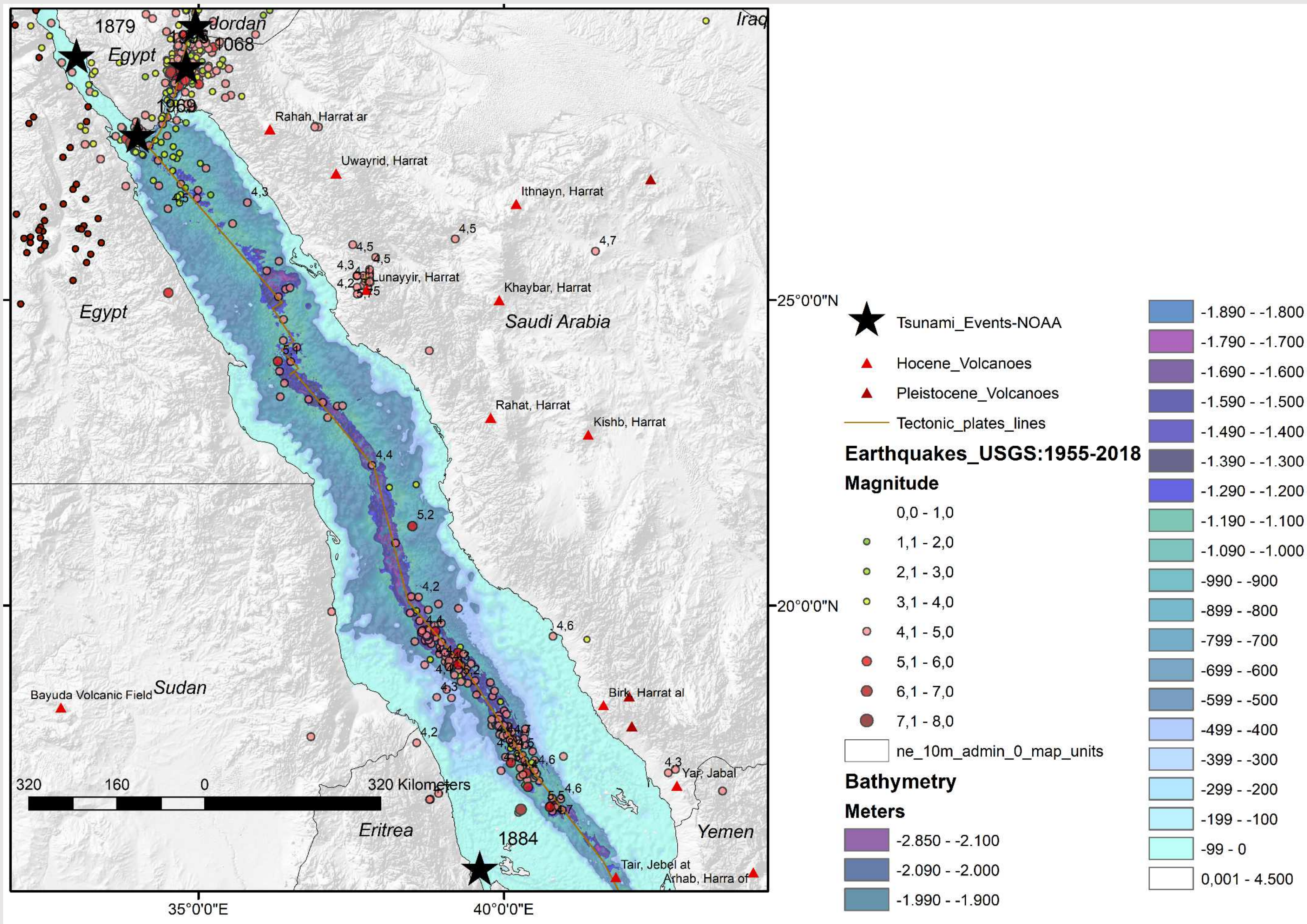
Terraces along river beds tracing uplifting movements ? Or just selective erosion of the strata?



The investigations of deep incised river beds and drainage systems within the lava outcrops might provide hints about vertical movements.

Tsunami events (blue stars) in the Red Sea as documented by NOAA

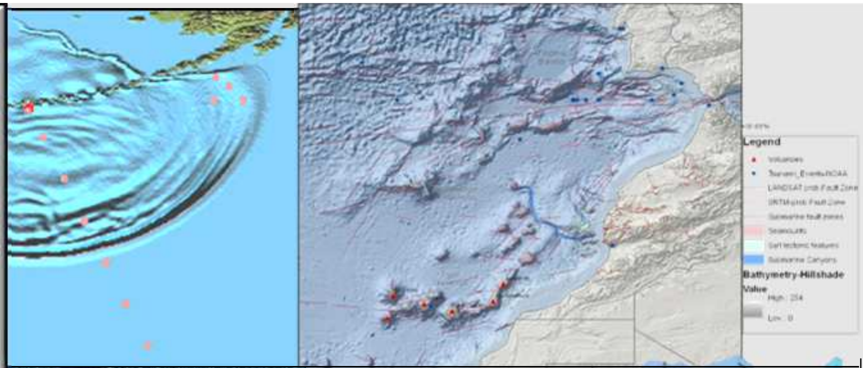
Bathymetric data: GEBCO



Sources of Tsunami Waves

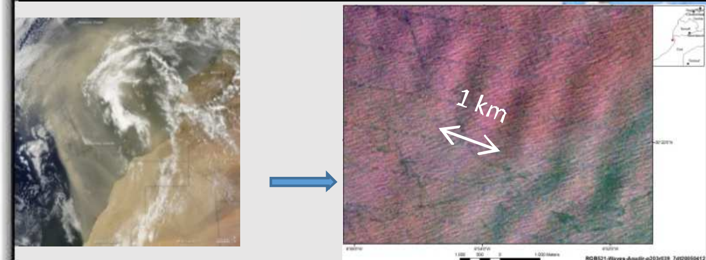
earthquakes due to movements along fault zones

volcanic activity



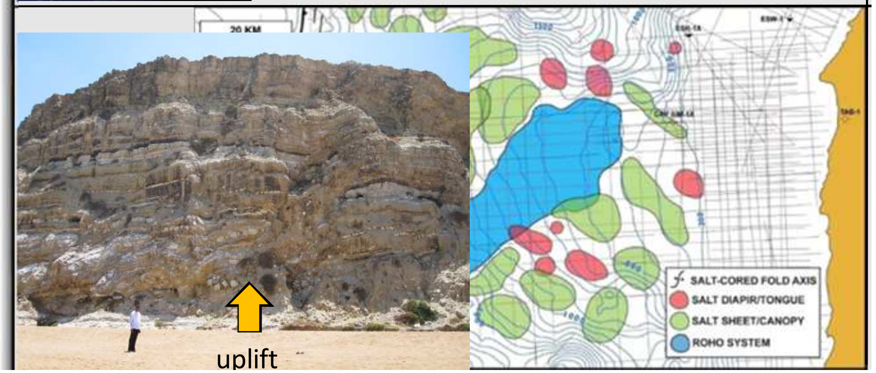
mass movements (turbidity currents, submarine slope failures of sea mounts, steep canyons and cliffs)

meteo-tsunamis



cosmic impact

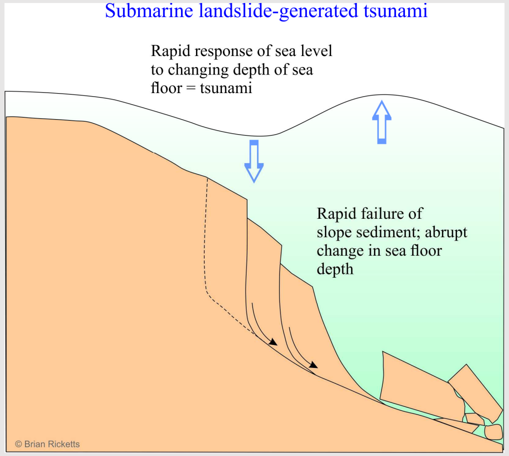
long-term subsurface instability due to salt domes, salt pillows, etc., causing earthquakes



Tsunami Sources in the Red Sea

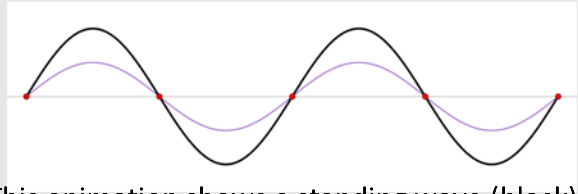
A series of potential tsunamigenic sources are considered in the Red Sea such as:

- related to major submarine earthquakes;
- volcanism (entry of pyroclastic flows and caldera collapse)
- submarine landslides
- meteo-tsunamis
- "seiche"-effects



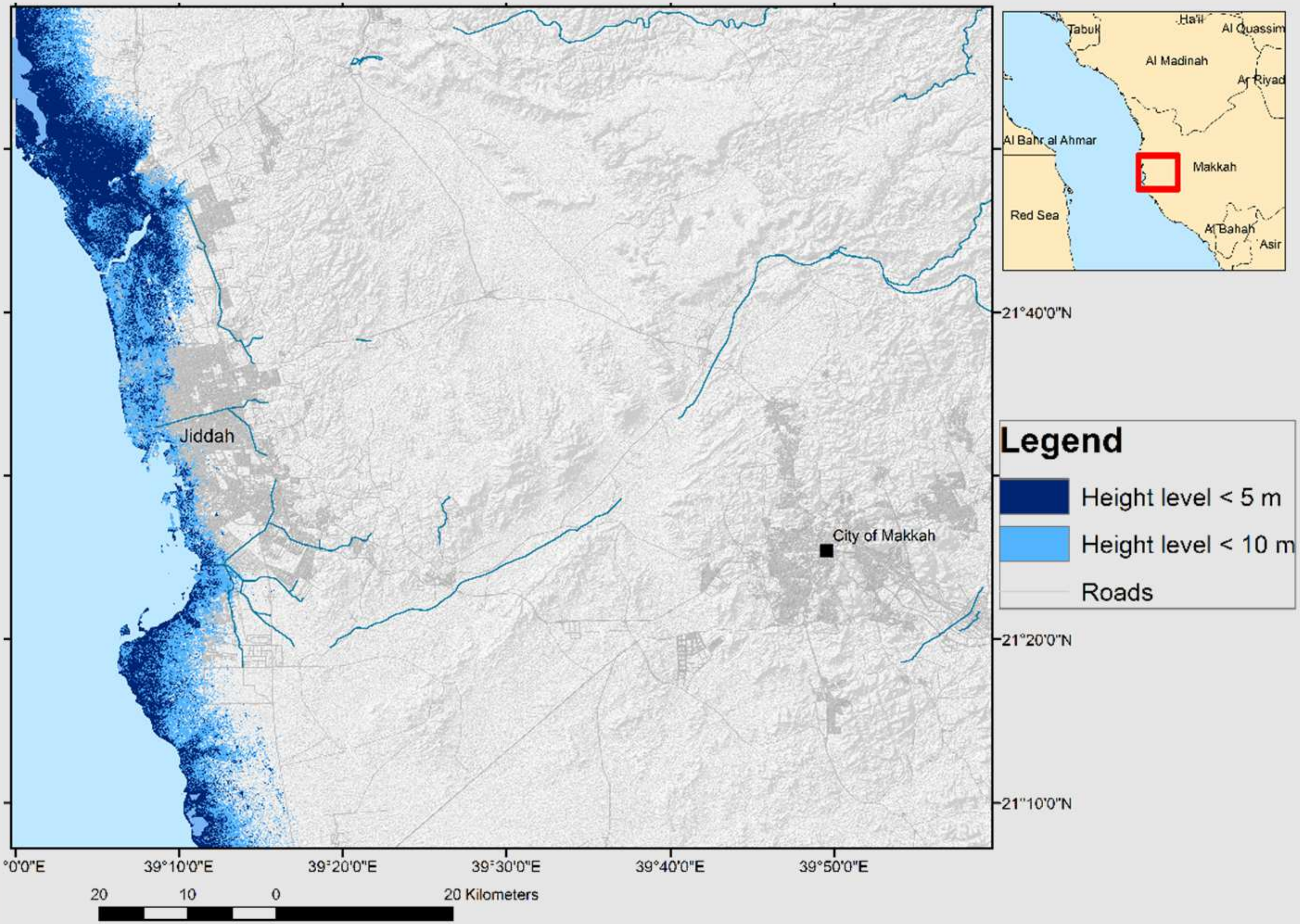
https://i0.wp.com/www.geological-digressions.com/wp-content/uploads/2016/11/submarine-landslide-tsunami.jpg?ssl=1

Winds and atmospheric pressure can contribute to the formation of both seiches and meteo-tsunamis; however, winds are typically more important to a seiche motion, while pressure often plays a substantial role in meteo-tsunami formation

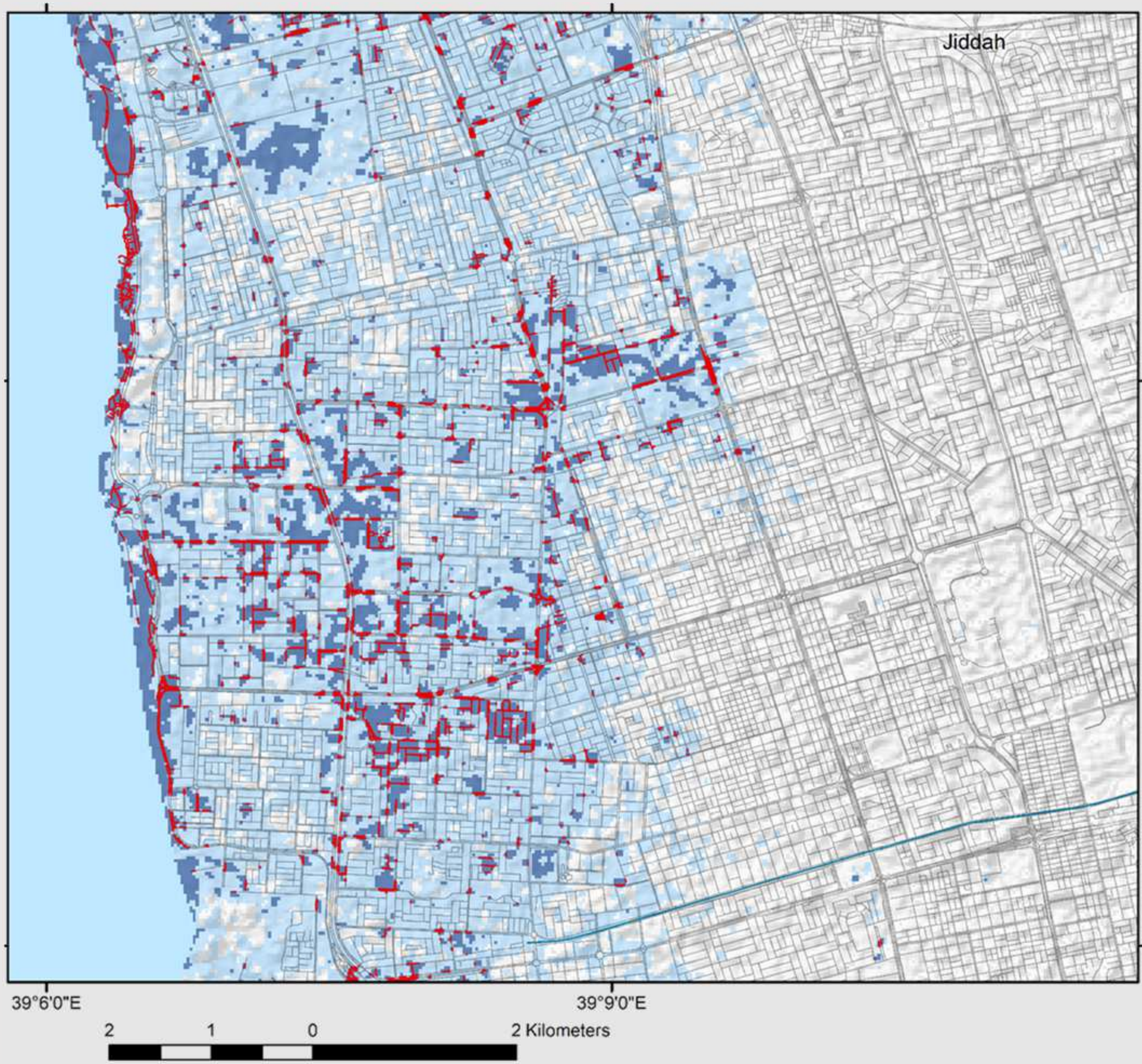


This animation shows a standing wave (black) depicted as a sum of two propagating waves traveling in opposite directions (blue and red). Similar in motion to a seesaw, a seiche is a standing wave in which the largest vertical oscillations are at each end of a body of water with very small oscillations at the "node," or center point, of the wave. Seiches are typically caused when strong winds and rapid changes in atmospheric pressure push water from one end of a body of water to the other. When the wind stops, the water rebounds to the other side of the enclosed area. The water then continues to oscillate back and forth for hours or even days. With an elongate shape (width of up to 355 km and a length of 2250 km) the prerequisite for seiche development in the Red Sea are favorable.
https://oceanservice.noaa.gov/facts/seiche.html

Height levels below 10 m calculated based on SRTM DEM data (30 m resolution)

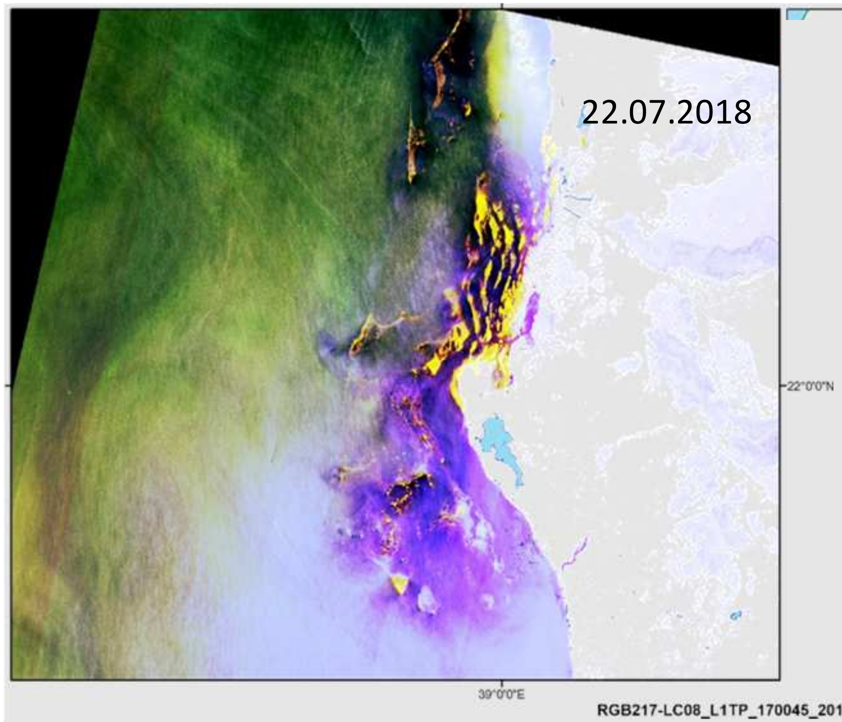


Road Segments < 5 m Height Level



This figure shows an example of the city of Jeddah, intersecting road-shapefiles with height levels below 5 m, assuming a tsunami wave-height of 5 meters as the leading parameter for tsunami preparedness. In case of high energetic flood waves from the Red Sea or in case of flash floods these road segments < 5m might be prone first to flooding due to their lowest height level.

Road segments below 5 m height level (red) in Jeddah calculated based on ALOS PALSAR DEM data (12.5 m resolution)



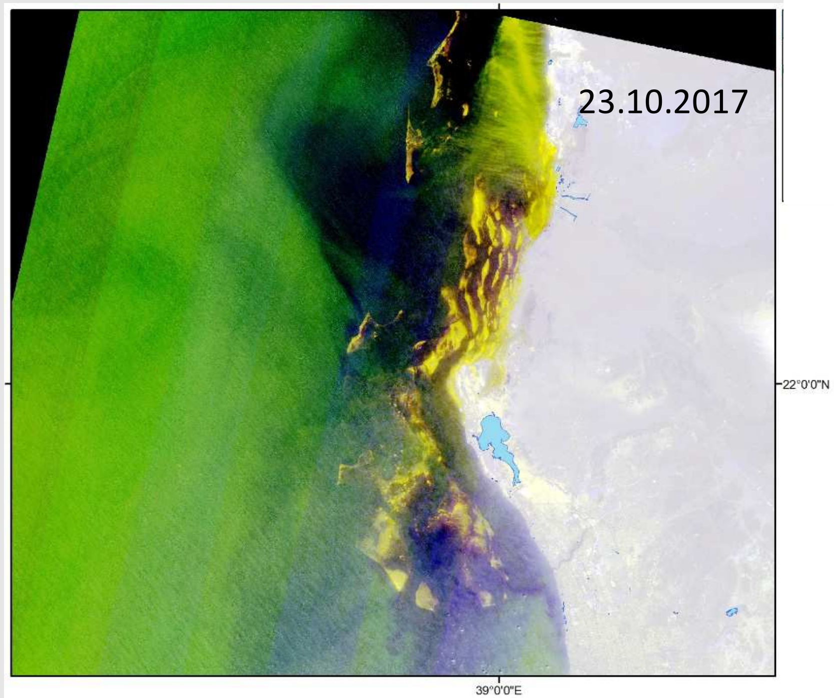
RGB217-LC08_L1TP_170045_20180722_20180731_01_T1

Wind Situation influencing the Steaming Pattern

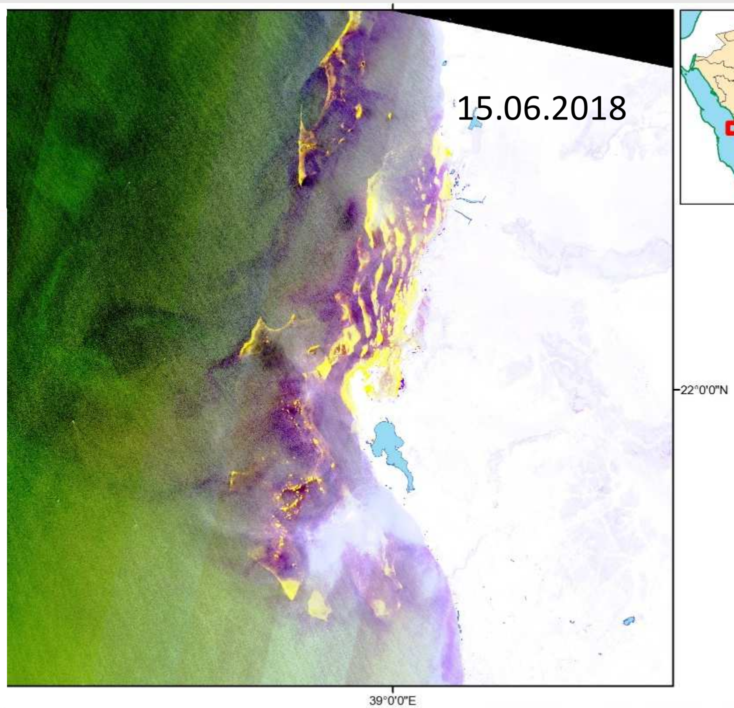
The source of tsunamis, the direction of the incoming waves, their height and energy cannot yet predicted. However, when analysing the influence of the coastal morphology on the streaming pattern in relation to wind and wave directions, it supports a better understanding of what might happen in case of high energetic flood waves.

Given that coastal flow is the product of a complex mix of factors (i.e. freshwater discharge, tides, winds in various frequency bands and the influence of motions imposed from seiche movements), coastal dynamics may be regarded as more regional.

Landsat 8-scenes reveal streaming pattern of the upper cm of the water surface.

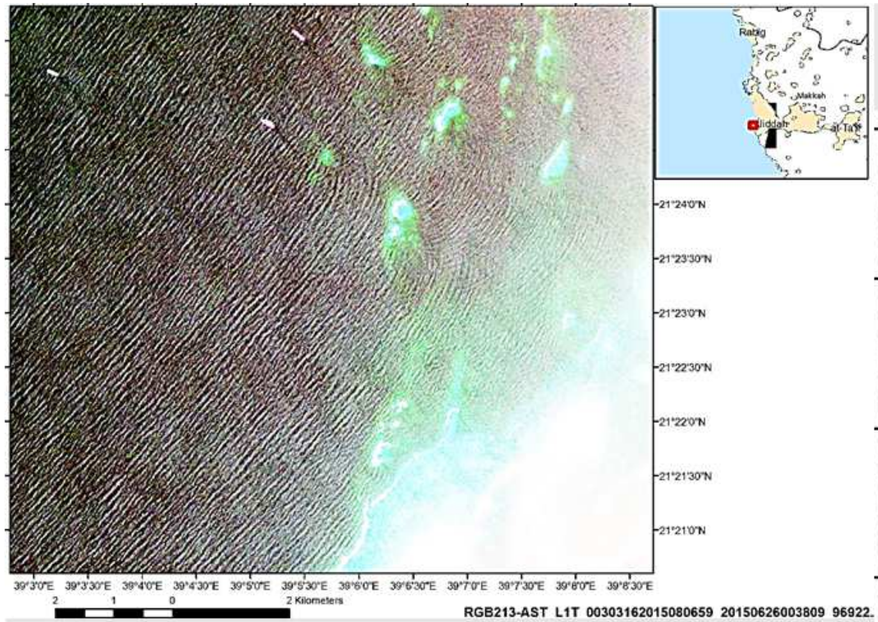


RGB217-LC08 L1TP 170045 20171007 20171023 01 T1

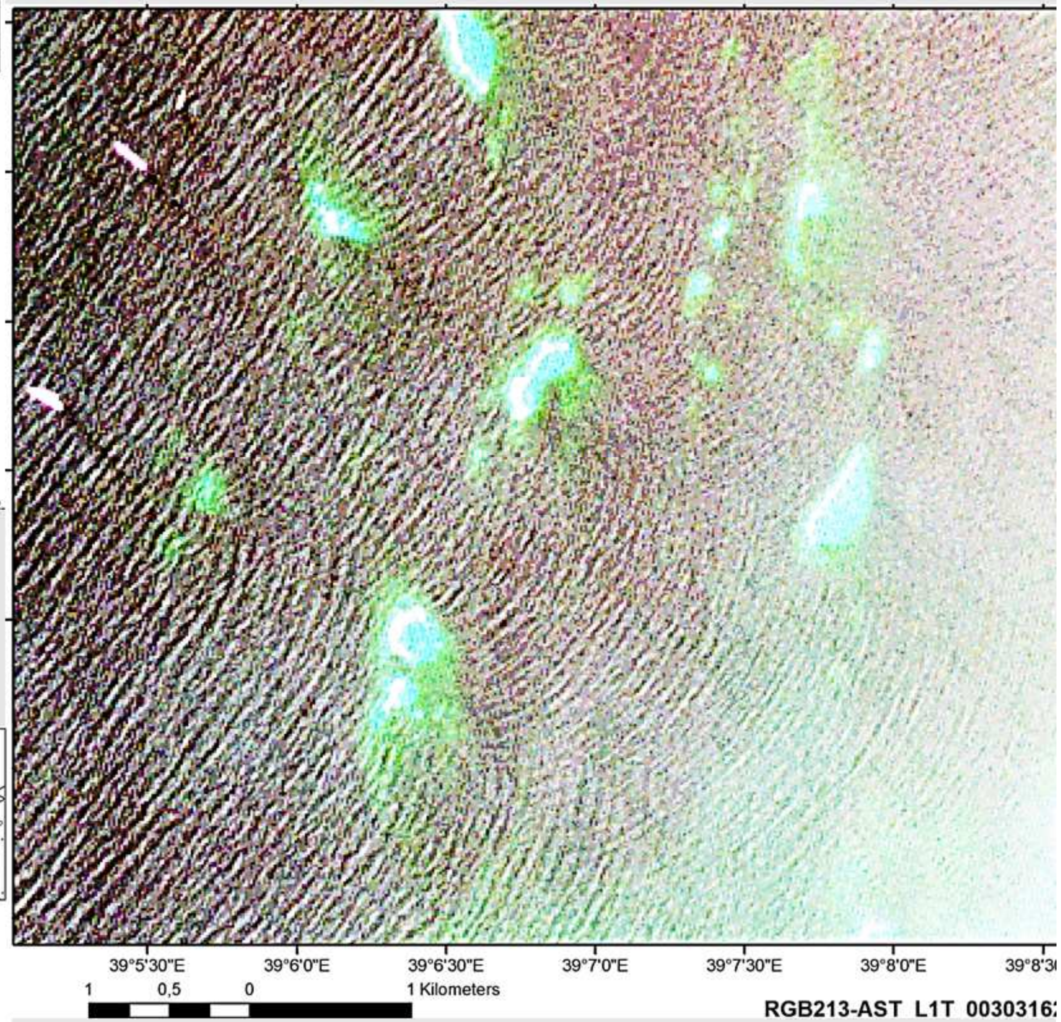


RGB217-LC08 L1TP 170045 20180604 20180615 01 T1

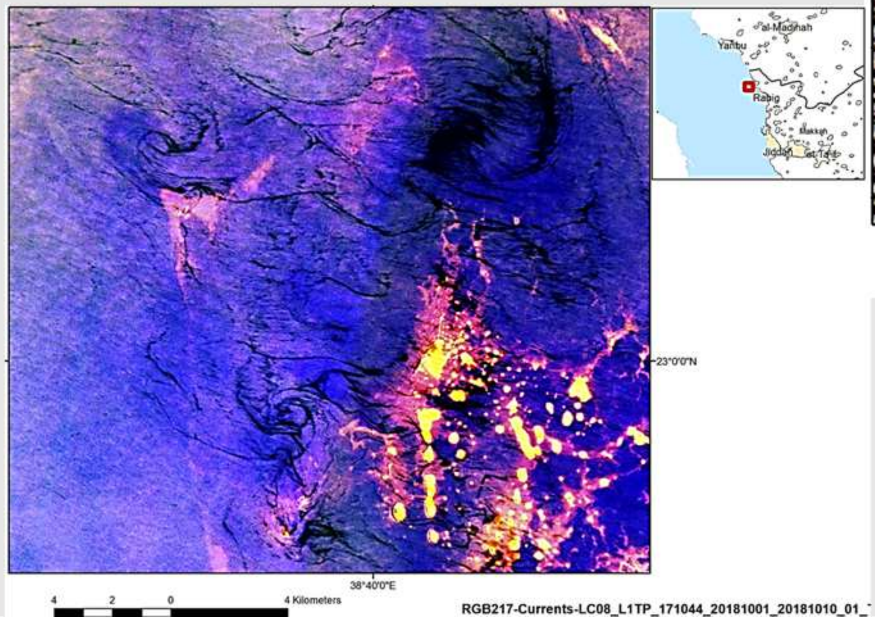
Islands influencing the wave pattern



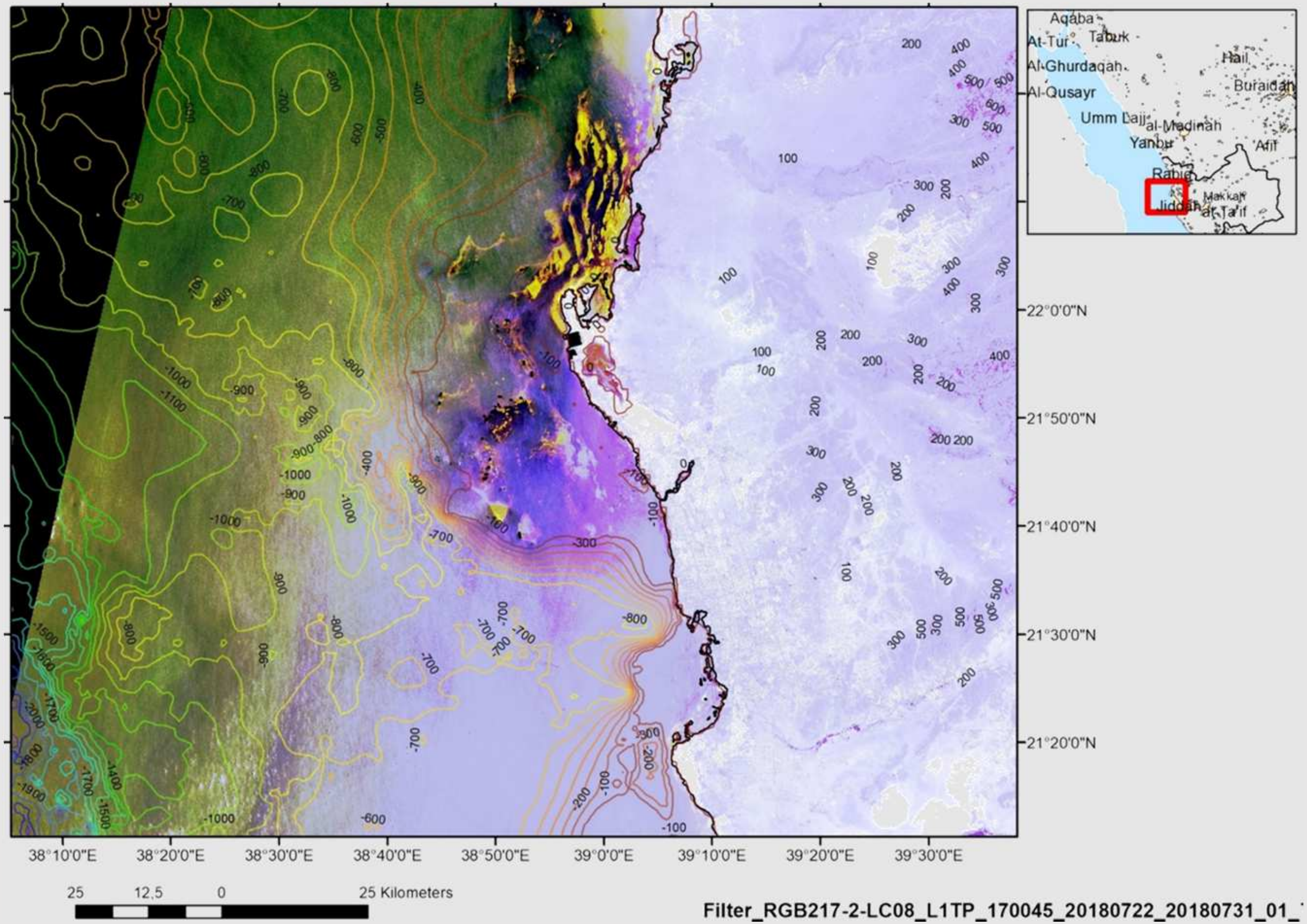
Aster Scene (06.08.2015)



The density, size and pattern of waves is modified by the islands. The waves are interfering each other towards the coast side.



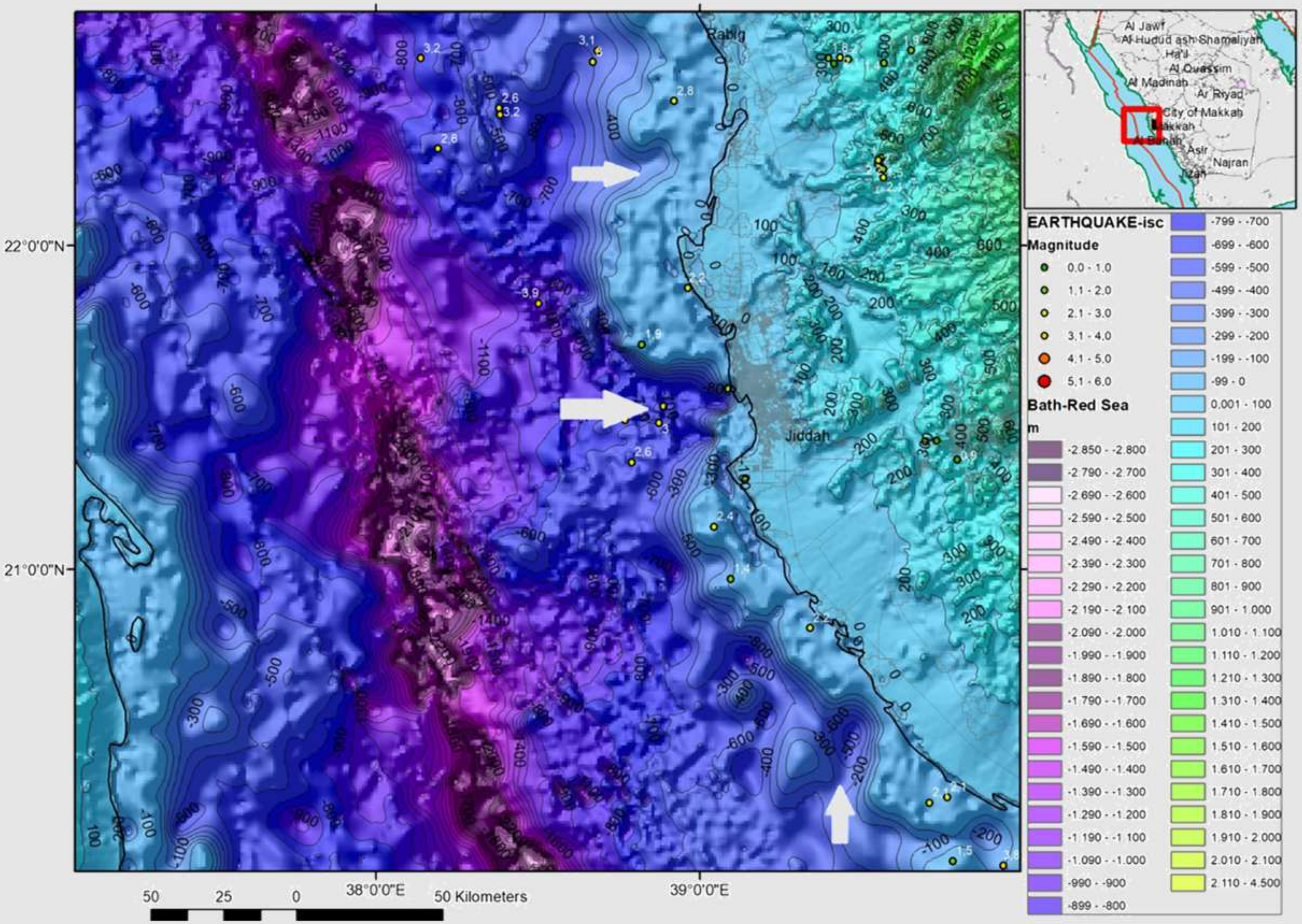
Seabottom Topography and Islands influencing the Stream Pattern



The bathymetric situation has an influence on the streaming pattern as well. This figure visualizes the bathymetric contour lines on the Landsat 8-scene and, thus, showing the difference in the streaming pattern visible on the satellite image from deeper areas to flat shelf areas.

Submarine valleys near the coast with potential focus of high energetic flood waves such as tsunami wave

The map was created based on GEBCO bathymetric data.



When analysing the coastal morphology and GEBCO bathymetric data deeper, submarine valleys /canyons can be observed that are partly oriented perpendicular towards the coast (white arrows). In case of high energetic flood waves such as tsunami waves caused by earthquakes, volcanic eruptions or submarine mass movements in the Red Sea the tsunami wave energies might be focused and concentrated along these valleys and, thus, in this case increasing the flooding extent in those coast segments.

Conclusions

The combination of the evaluation results based on satellite images and digital elevation data proved to be effective as an input for geo-hazard assessment. Prevention of damage related to natural hazards (such as extreme rainfall or earthquakes and resulting secondary effects) to human life and infrastructure requires preparedness and mitigation measurements that should be based on a regularly updated, GIS integrated data mining in order to create a data bank for the different geohazards. The frequent coverage of regularly available data such as Sentinel and Landsat are fundamental for the monitoring of the natural hazards in western Saudi Arabia.

Evaluations of the different satellite data from W-Saudi Arabia contribute to the identification of areas prone to geohazards, to the detection of the different types of hazards and of some of the causal factors influencing the disposition to the specific hazards. More detailed and partly new knowledge could be derived from the structural analysis of the remote sensing data.