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RESEARCH ARTICLE

Morpho-Tectonic and Satellite Image Interpretation for Identifying Gardez Fault in Afghanistan

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Abstract

Afghanistan experiences major geological changes since it is situated in a tectonically active area where the Eurasian and Indian plates collide. The influence of the convergence reaches hundreds of kilometers beyond the boundary of the southeastern plate. High mountain ranges are shaped by the faulting, folding, and uplifting of rocks; these formations are like a complicated jigsaw puzzle, with each piece revealing a different geological narrative. During fieldwork, using a Keyhole Markup Language Zipped (KMZ) file made comprehension easier. The left-lateral strike-slip character of the active Gardez fault was revealed by combining precise image analysis and correlation with satellite imagery, which was essential for comprehensive insights during laboratory processing. Our knowledge was significantly enhanced by the topographic representation of the Sarobi fault. The Cimmerian Kandahar arc and the active Chaman and Gardez faults to the west surrounded the Katawaz basin, which was the subject of the investigation. Geological boundaries were emphasized by ophiolites situated along the north-south axial strip towards the east. Pliocene sediments predominate, and recurring tremors indicate that block movements are still occurring, which could be a sign of impending large earthquakes. This study combines morpho-tectonic analysis with the interpretation of satellite images to reveal the characteristics of the active Gardez fault and comprehend the larger geological background of Afghanistan. The results provide insightful information on dynamic geological processes and have implications for future mitigation initiatives in the area as well as the assessment of seismic danger.

Keywords: Tectonic, Fault, GIS, RS

1. Introduction

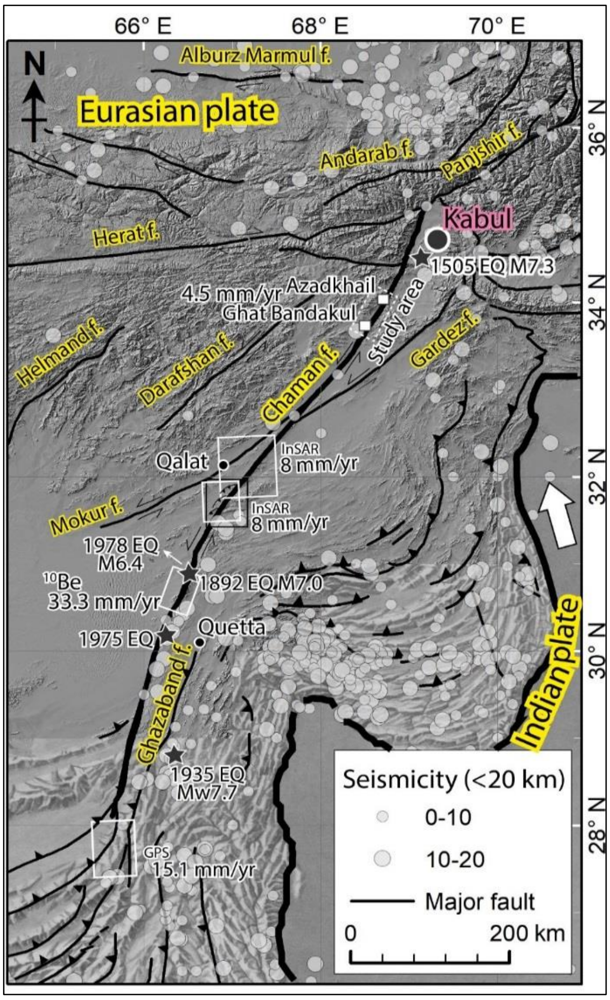
Numerous north-northeast trending shear zones and faults, especially at the boundary between the Variscan and Cimmerian domains, are characteristics of Afghanistan's northeast (Ruleman, Crone, Machette, Haller, & Rukstales, 2007). The Kabul block, which is about 300 km long and up to 70 km wide, is notable in this geological context (Siehl, 2017). Its interior is comparatively aseismic and shows no obvious evidence of late Quaternary faulting. The Paghman and Chaman left-lateral fault system, which serves as a barrier between western Afghanistan and central Afghanistan, defines the western edge (Zakeria Shnizai, 2020). Meanwhile, the Sarobi right-lateral and Gardez left-lateral faults, respectively, define the eastern and southern boundaries (Fig. 1).

Afghanistan has a complex geological environment, akin to a collage of structural blocks sutured into place on the expanding Eurasian plate after being divorced from other continental masses ((Benham et al., 2009; Siehl, 2017). Around the Kabul block, the main Chaman fault, which is situated roughly 650 km south across Pakistan, splits, expanding into the Paghman fault on the west and the Gardez, Sarobi, and other faults on the east (Ruleman et al., 2007). The Gardez fault, a transgressional plate boundary located within Afghanistan's Gardez City, is the subject of this study morphotectonic examination and identification (Fig. 1). The region is partitioned by deformation, with the Kirthar Suleiman front fault mostly accommodating thrust movements and the Chaman fault exhibiting around 26 mm/yr left-lateral strike-slip (Bernard, Shen-Tu, Holt, & Davis, 2000). The purpose of the study is to identify active faults, specifically the Gardez fault, by interpreting satellite images to pinpoint its precise location. To pinpoint the exact location of the fault, particularly in areas with high population density and residences constructed along fault traces, a KMZ file has been utilized.

Recent seismic activity in Afghanistan has made it imperative to research and document the traces of the Gardez fault since it runs beneath Kabul, the country's capital, and because the area is densely populated. On June 22, 2022, a significant earthquake with a magnitude of 6.1 occurred in the study area. It caused significant damage to the provinces of Khost, Paktika, and Gardez city, killing about 1050 people and wounding nearly 3000 more (Z Shnizai, Talebian, Valkanotis, & Walker, 2022). The terrane known as the Kabul block is included in the Kabul basin, which is situated in east-central Afghanistan (Zakeria Shnizai, 2020). It is surrounded by huge, active tectonic structures, such as the Hindukush suture in the north and the Sarobi fault in the east, making it tectonically active. The basin's western boundary is delimited by the Paghman fault. With more than 4 million residents, Kabul is more vulnerable to dangerous earthquakes and other natural disasters. Many people reside in buildings that were either built without sufficient seismic reinforcements or that were damaged during hostilities (Zakeria Shnizai, 2020). The main goal of this research is to examine the seismic hazards and active tectonics of the Kabul basin using topographic anaglyph pictures that are obtained from digital elevation models and satellite photographs. The study is to offer a detailed understanding of fault positions and lengths necessary for seismic hazard assessments and estimating the size of probable earthquakes surrounding the Kabul basin. Active and suspected active faults will be mapped using 3D anaglyph pictures and field observation.

2. Geology

Gardez is situated in the Kabul block's southern region. (Wheeler, Bufe, Johnson, Dart, & Norton, 2005) deduced a complex fault system in eastern Afghanistan from aerial images. The main fault is the left lateral Chaman fault, which has a north-east strike and a length of roughly 800 km. Wheeler estimated that the fault slips at a rate of about 15 mm/yr. While other writers have estimated displacements of between 300 and 500 km (Auden, 1974). Despite the fact that the Chaman fault, which is obviously active, divides the two distinctly geologic units (Tapponnier, Mattauer, Proust, & Cassaigneau, 1981). There are inadequate constraints on the quantitative estimates of rates or total displacement. The displacements and topography expression during the historic earthquake are evident (Griesbach, 1893). Though the Chaman fault may account for a sizable portion of India's motion relative to Eurasia. It is important for the relative motion not be parallel to the fault in order for it to not be a boundary on its own. According to (Wheeler et al., 2005), the Gardez fault is an active left lateral strike slip fault that runs roughly parallel to the Chaman fault (Fig. 1). On aerial images, the sarubi fault is well expressed topographically between it and the Chaman fault



(Prevot, Hatzfeld, Roecker, & Molnar, 1980).

Fig 1. Showing the overall study area and different fault traces that has been scattered in the area modified from (Zakeria Shnizai, Walker, & Tsutsumi, 2024).

Fig 2. Over all map of the Study Area. Red lines show various traces of Gardez Fault. The map is created by using Google Earth.

3. Research Methodology

The geographic coordinates of this area depict its location at latitude 33.6712414N and longitude 69.25128E. The images for this research were collected from Gardez city, Paktia province. This area is characterized by multiple fault traces, predominantly the Gardez fault (Zakeria Shnizai, 2020). The fault traces were captured from various angles across the area. These fault traces are significant from a geological perspective and are observable on the surface. To facilitate fieldwork, a KMZ file was generated for better visualization and plotting of fault traces in the map. The overall methodology of this research is shown in (Fig 3)

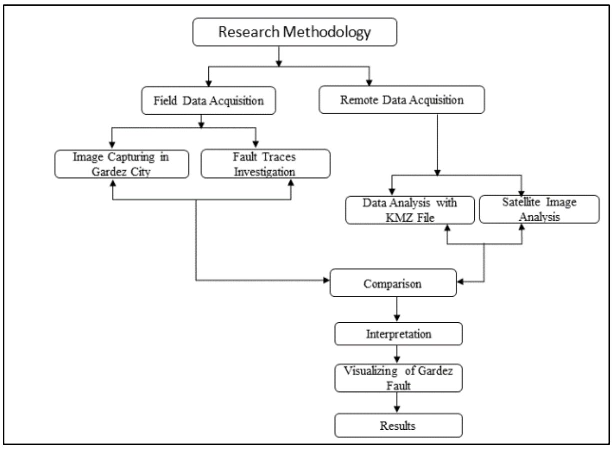


Fig 3. Flowchart of the methodology

3.1. Field Data Acquisition

In order to gather data for this study, images were taken in the Gardez city in the Paktia province, which is noted for having several fault traces associated with the Gardez fault. The faulted area was well covered by the images, which were taken from various perspectives. A Keyhole Markup Language Zipped (KMZ) file was made to make fieldwork easier and to help with the interpretation and identification of fault traces. In the field, this KMZ file was very helpful in plotting fault lines on Google Earth for reference and visualization (Fig. 2). A thorough map was created to illustrate the precise location and extent of the Gardez fault, which is located beneath the Kabul basin (Zakeria Shnizai et al., 2024) and may represent a threat. The study area focused on the areas that included faults and included the outskirts of Gardez city up to two kilometers to the left of the city. After investigating the fault traces in the isolated areas close to Gardez Regional Hospital, fresh sediments covered in sand and gravel were discovered (Fig. 4f and g). Interestingly, new sediments were found to be meandering along the fault path in several areas (Fig. 4f). Many fault traces, ranging in length from two to several kilometers, were visible in the KMZ file. These faults, which are mostly found in the southwest and have a variety of slopes and some river intersections, have been reported to outcrop many kilometers to the earth's surface as a result of erosive processes (Zakeria Shnizai et al., 2024). To confirm and record these fault traces and their features, fieldwork was important.

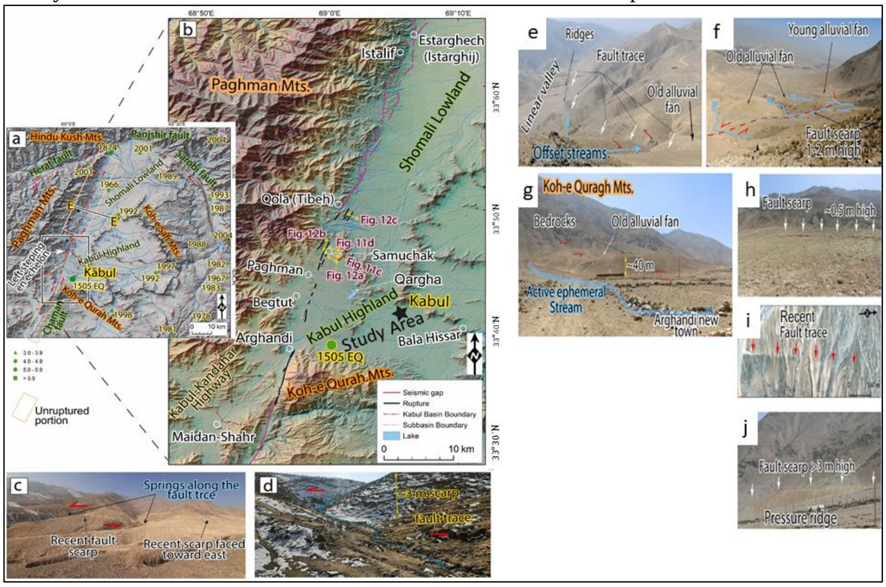


Fig 4. A) Gardez fault map, seismicity, and location of the surface rupture. b) a map showing the paghman, gardez, and chaman faults' surface rupture during the historical earthquake of 1505. The 1505 earthquake caused a surface breach that nearly runs straight down the Paghman and Garzez mountains. c) A recent fault scarp, offset streams, and springs are shown in a picture of the gardez fault strand. The fault track is indicated by yellow dotted lines. d) A field photograph showing the stream offset to the west of samuchak settlement and the gardez fault scarp. e) An oblique view towards gardhez of a linear valley southwest of Kabul City. f) a view of the passing streams and left-laterally displaced fans. g) a view of the fresh sediments and the arghandi alluvial fans, which are situated south of the main fan body. The strand of the Chaman fault has migrated northward. h) A possible link to the 1505 earthquake is a fault scarp on an alluvial fan that is less than 0.5 meters high. i) An aerial photograph of the Chaman fault, displaying a distinct fault trace. g) A pressure ridge located in the study region along the Chaman fault.

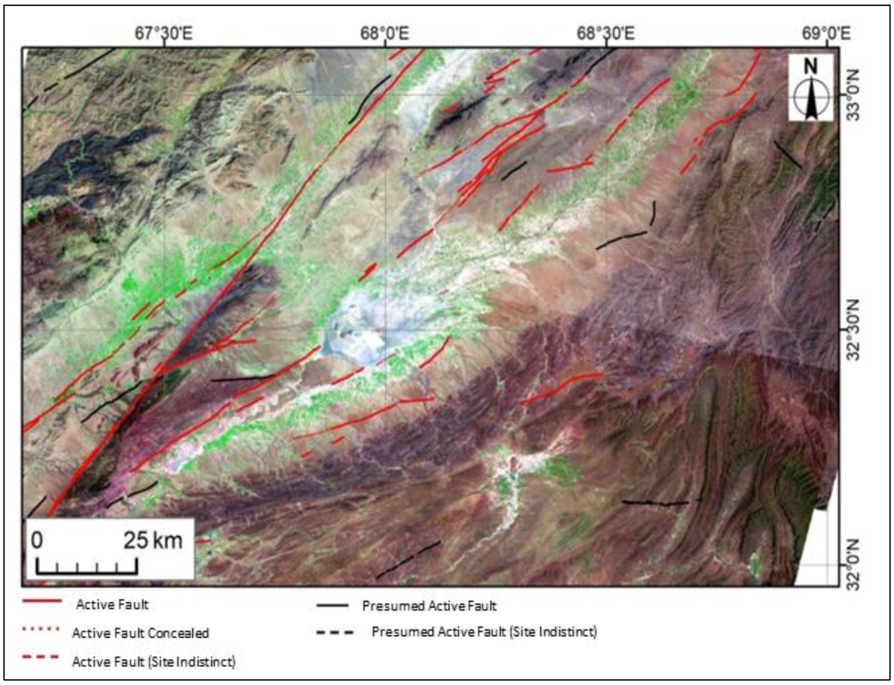


Fig 5. Active Fault: Areas with notable ground deformation suggestive of active faulting are identified by the Interferometric synthetic aperture radar (InSAR) data (Al Ghiffari, Nugroho, Ramadhan, Noor, & Wicaksono, 2024; Zhou, Chang, & Li, 2009). Typically, these regions show distinct surface displacement patterns that are in line with the continuous tectonic activity along the Gardez Fault. Active Fault Concealed: Underneath surface features like plants or man-made structures, there are situations where the active fault remains hidden. The InSAR data shows subsurface deformation patterns that imply the presence of an active fault underneath, even in the absence of any surface expression (Ulin, Taufik, & Anjasmara, 2019; Yusoff et al., 2020). Active Fault Site Indistinct: It can be difficult to pinpoint the precise site of the fault trace in some Gardez Fault segments due to less noticeable deformation patterns. In these regions, where fault activity can be less obvious, the InSAR data reveals faint traces of ground movement (Zhou et al., 2009). Presumed Active Fault: Area's where geological and geomorphological signs strongly imply the existence of an active fault. While there may not be direct evidence, the InSAR data lends further credence to the hypothesis of fault activity in these regions. Presumed Active Fault (Site Indistinct): Based on geological factors, these regions are assumed to be connected to active faulting, much as the preceding category. However, because of the fault's limited surface manifestation, its precise location and features are still unknown. The knowledge of fault activity in these unclear places is improved with the use of the InSAR data.

The research also examined the Katawaz basin's tectonic geomorphology by examining satellite images taken at the given coordinates (33.6750333N, 69.25469E). To emphasize important geomorphic features, these images were georeferenced and altered in ArcMap. The fieldwork encompassed a wider area, with a particular emphasis on the Gardez fault. Here, active and suspected active faults were mapped using proven methodologies from Japan, based on geomorphic criteria typically used for active fault mapping (Zakeria Shnizai, 2020). In addition, the analysis took into account the points where all of Afghanistan's active faults cross, highlighting the possible seismic risks in the area. Different active faults were displayed in (Fig. 1 and 4), which also showed how the Indian plate is moving in relation to the Eurasian plate and how this motion affects the local topography by slicing through rivers (Molnar & Tapponnier, 1977). The 18-month period of recorded earthquake experiences by the locals sheds further light on the activity of these faults. To map and comprehend the geological features and fault lines in the Gardez region and the larger Katawaz basin, a thorough technique that combined the analysis of satellite imagery, the use of KMZ files, and substantial fieldwork was employed.

3.2. Remote Data Acquisition Methodology

In order to analyze the Gardez fault, the researchers used a remote data collecting methodology that combined fieldwork with analysis of satellite images. The area's geographic coordinates are longitude 69.25128E and latitude 33.6712414N. In order to locate fault traces and characteristics, field study required creating a schematic map and taking pictures from various locations (Schwartz & Coppersmith, 1984). There was a KMZ file created to direct fieldwork. A polygon was created and stored in Google Earth to create the KMZ file, which made it easier to interpret faults in the various communities of Gardez (Fig. 4). A major contribution came from satellite images, which was analyzed using False Color Composite (FCC) in several bands (Patra, Shekher, Solanki, Ramachandran, & Krishnan, 2006). After processing several images, the results were compared to field photographs. The interpretation was wide-ranging, indicating fault lines in regions heavily inhabited by homes and villages.

It became clear that the people would be at risk, and comparisons with known circumstances in other fault zones, such as Herat, were made. Landsat 8 provided more insight into the interpretation of satellite images (Adiri et al., 2017), displaying a range of fault traces in the Gardez region (Fig. 5 and 6). An essential component of the study was fieldwork, which required traveling to various locations to interpret the Gardez fault. The comprehensive map demonstrated Gardez wide covering of faults. For the purpose of interpreting satellite images, the study additionally made use of False-Color Composites and Digital Elevation Model (DEM) (Hidayatillah, Nurcahyo, Muliawan, & Endarsih, 2024) (Fig. 7) . The figures presented the Gardez fault in different contexts, providing a comprehensive view of fault traces and their extension.

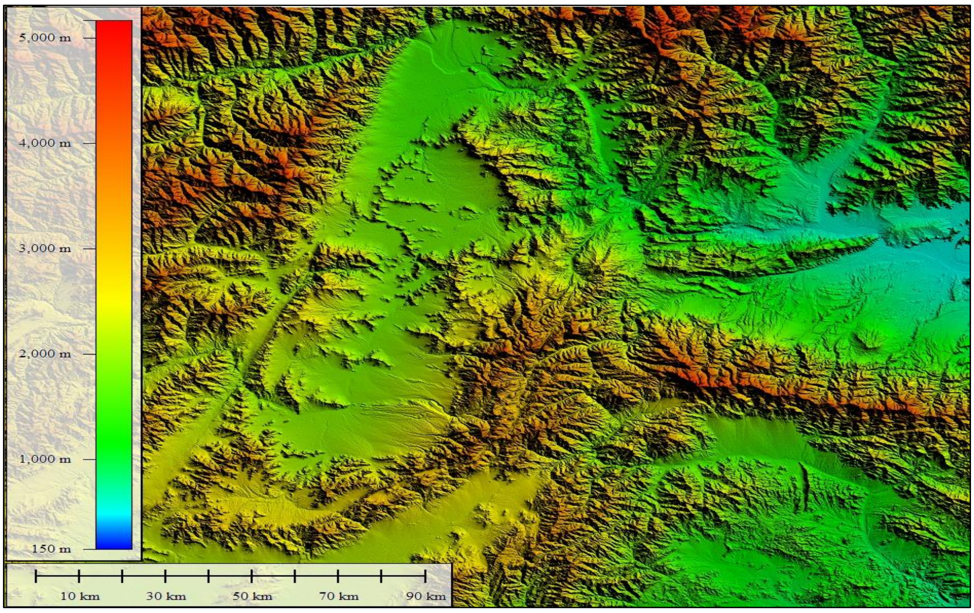


Fig 7. Digital Elevation Model of the study area. 10 m resolution.

4. Results and Discussion

The research findings have been extensively deliberated, covering several facets of the investigation. The active Gardez fault was the main topic of interpretation and is the center of this discussion. The research's conclusions have also been thoroughly discussed. Understanding the risks posed by the faults in the Gardez area required fieldwork. The precise morphology of the fault traces was revealed by correlating the identification of several fault traces in the field with locus maps and satellite pictures. Every defect trace was measured with painstaking attention to detail. The results indicated that the fault traces observed in satellite images precisely matched their positions and morphologies in the field. The exploration of Afghanistan's geological environment yielded a more comprehensive understanding of the seismic activity in the area (Zakeria Shnizai et al., 2024). As previously mentioned the most recent earthquake >6 magnitude damaged thousands of people (Zakeria Shnizai et al., 2024). The convergence of the Indian and Eurasian plates, which places the nation in a geologically active area, was emphasized. We discussed about the ongoing motions along active faults that are a result of Afghanistan's intricate geological mosaic. The Gardez fault was the main subject of the study, which emphasized the fault's populated position and the fact that fault lines ran into residential areas. It was shown how dangerous an active fault could be in such a densely populated area (Allen et al., 1991). We discussed in detail the left lateral Gardez fault, which defines the southeast edge of the Kabul block against the Katawaz basin.

To help interpret the Gardez fault, photographs were obtained during field visits. GPS data DD COORDINATES

(33.6712414 69.25128), DMS COORDINATES (33°40'0.12" N 69°19'59.88" E), GEOHASH COORDINATES (ttcr98yfw), UTM COORDINATES (42S 530899.29190646 3725251.158454) was successfully integrated into the study, and fault trace coordinates were noted in a notebook. The Kabul-Gardez highway presented difficulties that made it difficult to investigate some fault traces. One noteworthy finding was the prevalence of fault traces in villages, which reminded observers of a similar situation in Herat, where deaths and casualties were associated with substandard infrastructure. The extensive conversation encompassed the understanding of the Gardez fault, the risks connected to active faults in densely inhabited regions (Slater & Niemi, 2003), and more general geological perspectives on the seismic activity in Afghanistan. The relevant authorities were also supplied with recommendations derived from the findings for their consideration.

5. Conclusion and Recommendations

We provide a summary of the main findings from our study in this final chapter. Our goal was to offer the first thorough account of active faults in the Katawaz Basin, Afghanistan. The Gardez fault, a large left-lateral strike-slip fault located in the Katawaz basin, was the main target of our mapping efforts. Several minor problems were also found during the investigation in addition to this significant one. The Chaman fault predominantly accommodates the left-lateral shear in the region. These faults are significant because of their obvious effects on landforms and the way they have displaced Quaternary deposits. The length of the plotted faults indicates their seismic potential, capable of creating earthquakes larger than Mw 6.9. According to local sources, earthquakes occur regularly in the Katawaz basin, where this study emphasizes the significance of comprehending seismic threats. Additional research is essential to provide the ground for a more thorough seismic hazard assessment in the Katawaz basin. It is specifically advised to conduct trenching investigations along the northern Chaman fault and the Gardez fault. Even though we now know exactly where the faults are, trenching investigations are still necessary since there is a dearth of information regarding past earthquakes. These investigations will shed light on the time of the most recent seismic occurrences in the area as well as the interval between significant surface-rupturing earthquakes. In conclusion, our study adds important knowledge regarding active faults in the Katawaz Basin, with a special emphasis on the Gardez fault. By improving our knowledge of seismic dangers, the trenching investigation proposals hope to pave the way for future evaluations and mitigation initiatives in earthquake-prone areas.

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