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Geomorphology of the Ceyhan River lower plain (Adana Region, Turkey)

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ABSTRACT

We present a geomorphological map (Main Map) of the lower plain of the Ceyhan River (Adana province, Turkey). Data from three field campaigns and remote sensing observations were managed in a GIS to produce a 1:25,000 scale map. The area, mostly formed by alluvial sediments, is characterized by intense fluvial dynamics with superimposed agricultural activity. Erosional processes prevail on rocky ridges partially bordering the plain on the north-eastern side. The alluvial plain is flanked by large alluvial fans on its eastern side, whereas the western limit consists of a smoothed and undistinguishable watershed. Alluvial and deltaic deposits close to the river mouth are bordered southward by nested coastal dunes, lagoons, swamps and marshes punctuating the coastal belt. This area was an important historical site, as documented by evidence of settlements from the Neolithic. The map is a useful tool to support further archaeological research.

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KEYWORDS

Geomorphology; alluvial plain; Ceyhan River; Turkey

1. Introduction

Geomorphological studies of alluvial plains characterized by ancient settlements are often within the context of the Mediterranean basin (Amorosi et al., 2013; Anthony, Marriner, & Morhange, 2014; Bini et al., 2012, 2015; Bony, Marriner, Morhange, Kaniewski, & Perinçek, 2012, 2015; Brückner, 1996; Jean-François, 2011; Marriner, Morhange, Borschneck, & Flaux, 2012; Vött, Brückner, Handl, & Schriever, 2006, 2007; Zanchetta, Bini, Cremaschi, Magny, & Sadori, 2013), as the settlements could represent a starting point for geoarchaeological studies providing new data on human–environment interactions in the history of Mediterranean civilization. The study area here is related to the eastern part of the Çukurova alluvial plain in the Adana region. Çukurova is considered one of the most important alluvial plains in Mediterranean Turkey, not only for its large extent, population density and importance for economic activity but also for its noteworthy history. It was an important historical site, as documented by evidence of settlements from the Neolithic (Salmeri & D'Agata, 2011; Seton-Williams, 1954).

The Çukurova plain, surrounded by the Misis Mountains in the East and the Tauride Mountain belt in the North and West, is formed by the Taurus, Seyhan and Ceyhan rivers (Figure 1), which contributed to fill the tectonic depression of the Adana Basin with a complex history of aggradation and superimposition (Gürbüz, 1999; Kozlu, 1987; Williams, Unlüğenç,

Kelling, & Demirkol, 1995). While the principal geomorphological characteristics of the Çukurova plain were already delineated, with particular regard to the coastal belt and to the areas surrounding the cities of Adana and Mersin (Aksu, Ulug, Piper, Konuk, & Turgut, 1992; Bal & Demirkol, 1987; Erinc, 1978; Erol, 2003; Evans, 1971), the eastern part of the Çukurova plain is less studied. The aim of this work is to map the main geomorphological features characterizing the Ceyhan plain (Main Map), in order to provide a base for future geoarchaeological research and to place the existing information within the context of the alluvial plain evolution.

2. Regional geology

The Çukurova plain is in the southern part of the Neogene Adana Basin, which lies in the intersection region of the Arabia, Africa, and Anatolia Plates (Figure 2). It is bounded by the Ecemis Fault Zone in the North-West, and by the Karataş Fault Zone along the structural high formed by the Misis mountain range in the South-East (Duman & Emre, 2013; Over, Ozden, & Can Unlugenc, 2004). The entire area is characterized by intense seismicity, including destructive earthquakes, as documented by historical records (Ambra-seys & Jackson, 1998; Nalbant, McCloskey, Steacy, & Barka, 2002). The earthquake of 1998 was linked to the Misis fault: it caused casualties and building damage in Adana city and in the Adana Industrial

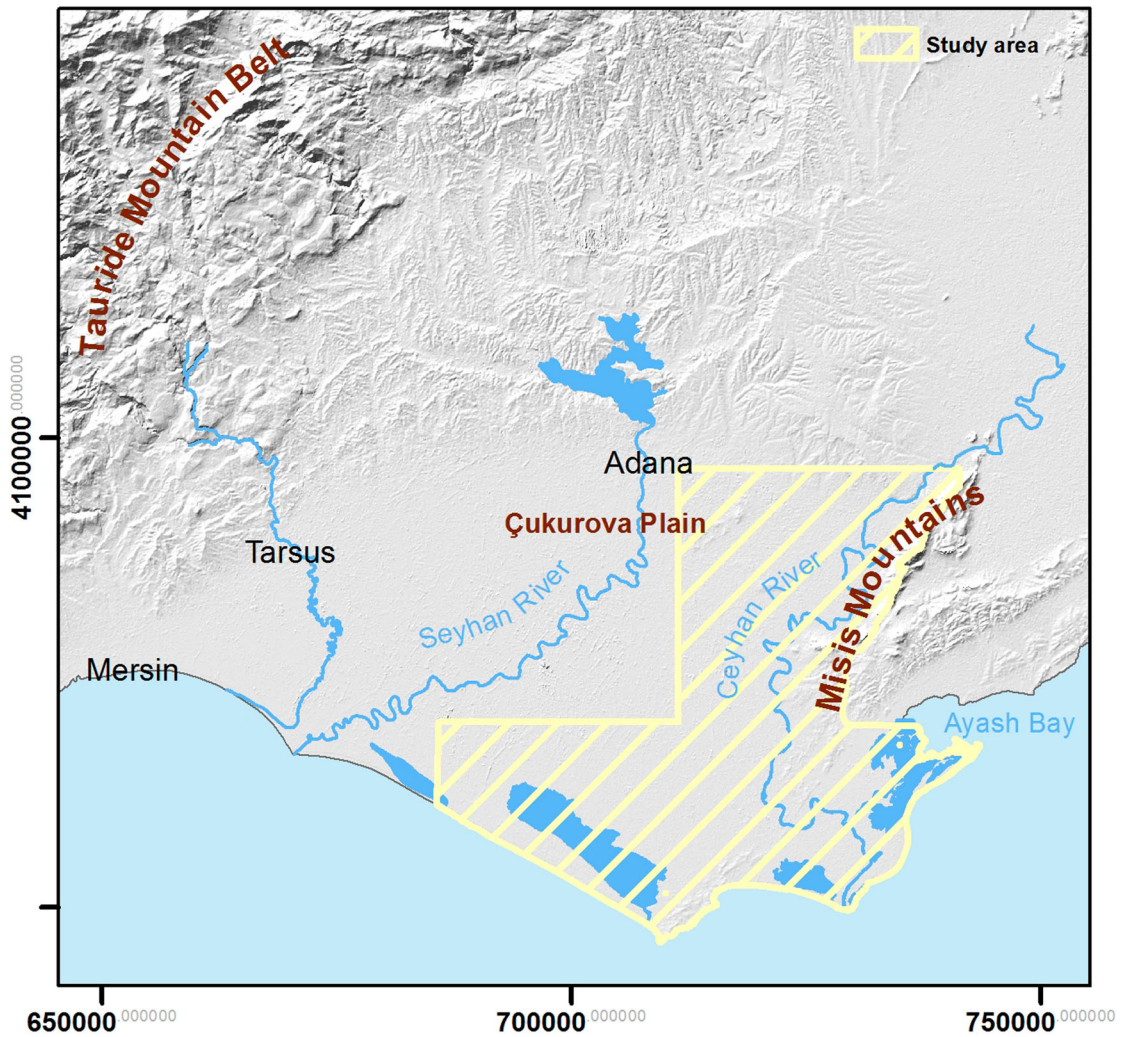


Figure 1. Regional setting of the study area (yellow box).

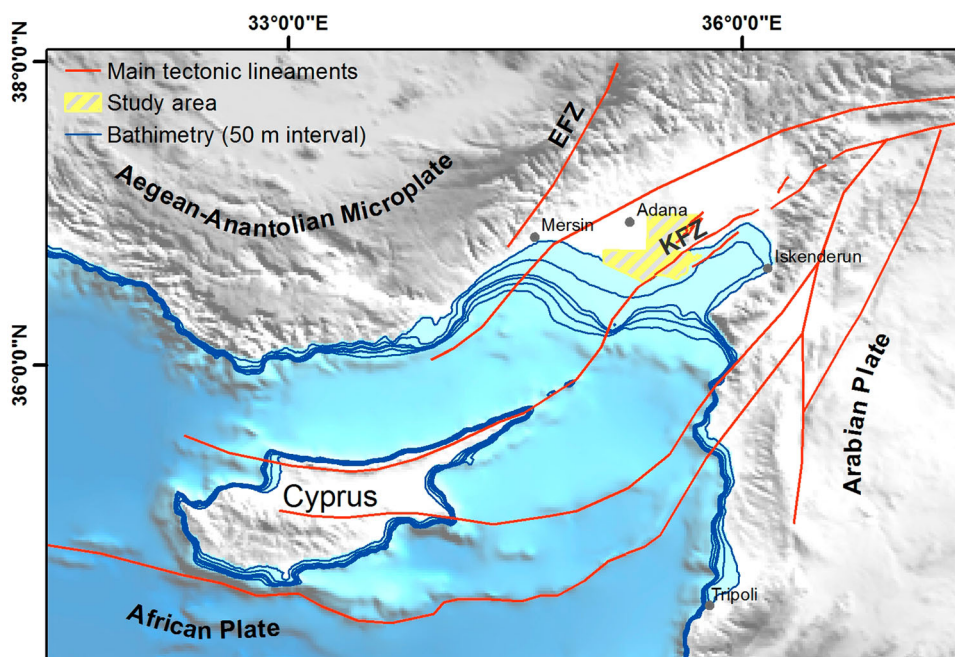


Figure 2. Simplified tectonic sketch map showing major fault lineaments (modified from Walsh-Kennedy et al., 2014). The study area appears in yellow. EFZ: Ecmis Fault Zone and KFZ: Karataş Fault Zone.

Zone, along with soil liquefaction and river bank collapse in the area of Abdioglu village (Adalier & Aydinoglu, 2001; Bozkurt, 2001; Bulut et al., 2012; Gülkan, 1998; Over et al., 2004; Ulusay & Kuru, 2004).

The study area extends for about 1500 km² downstream from the rocky narrow of YilanKalesi, along the lower Ceyhan river basin as far as the Mediterranean Sea. It is bordered by the Misis Mountain Range in the North-East and by the discontinuous and faint watershed between the Seyhan and Ceyhan rivers in the West. Owing to the complex tectono-stratigraphic evolution of the basin, the substrate outcrops in the structural high of the Misis Mountain Range and in the southernmost dorsal in Karatas. The first dorsal mainly consists of carbonate and silicoclastic rocks deformed and metamorphosed by Palaeozoic and Mesozoic tectonic phases, together with an ophiolitic mélangé (Robertson, Unlügenç, İnan, & Tasli, 2004). In the latter, the Neogene series outcrops, and is composed by the Kuzgun (Tortonian), a shallow marine to non-marine formation (sandstone and mudstone) and by the Handere formation (Messinian-Pliocene), which comprises fluvial sediments, shallow marine and lagoon sediments (claystones, sandstones and mudstones with conglomerates) (Yetiş, 1988). Quaternary deposits formed by fluvial deposits (gravel, sand, silt and clay layers) discordantly overlie the Neogene formations.

The plain is mainly built by alluvial variable grain-size deposits due to the rapid decrease of the Ceyhan hydraulic gradient, leading to the accumulation of an unconsolidated alluvial deposit at least 300 m thick probably during the last 0.6 Ma, as recorded by deep boreholes for hydrogeological investigations (General Directorate of State Hydraulic Works of Turkey [DSI], 1984) and by geophysical prospecting for hydrocarbon research (Aksu et al., 1992; Burton-Ferguson, Aksu, Calon, & Hall, 2005).

Before construction of the Aslantaş Dam in 1984 the annual sediment load of the Ceyhan was 5.5 million tons (United Nations database <http://www.fao.org/ag/agl/aglw/sediment/>), producing an important coastal progradation in the mouth area (Aksu et al., 1992), with nested coastal dunes, lagoons, swamps and marshes flanking the river mouth. The sediment load dramatically decreased after the construction of the dam and the coast now experiences erosion phenomena (e.g. Çetin, Bal, & Demirkol, 1999).

The climate in the region is predominantly Mediterranean with mean annual values of ~700 mm in precipitation and 18°C in temperature. Summers are hot and dry, with temperatures above 30°C. Spring and autumn are generally mild, but during both seasons sudden hot and cold spells frequently occur (Turkish State Meteorological Service). The tide regime in the area is low, with the largest known tidal range at Karataş of 0.48 m (<https://www.tide-forecast.com>).

3. Methods

In order to better understand the relationship between human settlements and plain evolution, three field campaigns were conducted in October 2012/2013 and April 2015 as part of the Cilicia Survey Project (Salmeri & D'Agata, 2011). During the geomorphological surveys, we mapped most of the features by means of a global position system receiver for better localization, with final data management in a geographic information system (GIS), using the methodologies described in Isola et al. (2011). We verified and improved the survey data using remote sensing analysis performed with Landsat7 ETM+ (30 m spatial resolution) optical imagery and Quick Bird imagery (QB02 sensor and Pan_MS1 band, 60 cm spatial resolution). In order to highlight geological characteristics, we processed different combinations of spectral bands from Landsat imagery (near infrared-red-green, 432; near infrared-medium infrared-red, 453; and short-wave infrared-near infrared-green, 742). Band 8 (15 m spatial resolution) was used to generate panchromatic image sharpening, in order to increase the geometric resolution of the red, green, blue composites.

The final dataset was then processed in a GIS. The final vector dataset was draped on shaded images derived from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (DEM), with 30 m cell size. We used imagery analysis to draw main hydrological features like those of the Ceyhan River and also artificial channels, while we mapped minor features during fieldwork.

The vector data were organized in a spatial database and includes polygon feature classes (e.g. bedrock outcropping, deposits, quarries), line feature classes (e.g. gullies, scarps, watershed) and point feature classes (traces of ancient exploitation activity, elevation points derived from the ASTER DEM). Each symbol is generally related to a specific form but, in some cases, forms with composite genesis are shown. In particular, calcrete (or caliches) and tufa deposits are present over the Kuzgun and Handere formations (Kapur, Yaman, Go, & Yetiş, 1993) in the Misis area, or in the Misis Mountain Ridge. In these areas, it is not always obvious to separate these two different kinds of chemical precipitates and, as they usually occur on top of the paleosurfaces, we represent them by using a transparent common symbol, draped over the different morphological features mapped.

Bedrock is divided into three different main categories, while forms and deposits are grouped in four main morphological units:

- Slope forms and deposits, including debris slope deposits, and gently sloping inclined bedrock surfaces sometimes covered by tufa and/or calcrete

- Fluvial forms and deposits, including linear forms as fluvial scarps, palaeochannels, watersheds, gullies as well as areal forms such as oxbow lakes, alluvial and colluvial deposits, fluvial terraces and alluvial fans;
- Coastal and lagoon forms and deposits, including the modern delta plain deposits, dunes, lagoons, marsh and marine deposits.
- Anthropogenic forms, including urban area and exploitation areas, modern quarries are drawn with areal extent while the ancient traces of exploitation are indicated with a symbol.

In the following, we describe only the main morphological elements characterizing the geomorphology of the lower basin of the Ceyhan.

3.1. Terrace-like surfaces with tufa and/or calcrete

Calcrete, a pedogenetic to non-pedogenetic groundwater accumulation of calcium carbonate (Retallack, 1990), has already been described in the Misis and Mersin area (Eren, 2011; Eren & Hatipoglu-Bagci, 2010; Kapur et al., 1993). The profiles develop from discrete carbonate nodules to coalesced, indurated hardpan horizons, often characterized by overprinting brecciation and re-cementation that contribute to preserving the sub-plain surface of the terraces. This element has widespread diffusion in the Misis area.

In the Adana Industrial Zone, the calcrete hardpan extensively covers ridges and small depressions of the Handere Formation and, consequently, the ground surface assumes a terrace-like morphology, slightly inclined to the south and segmented by stream erosion. The calcrete profile is formed by an upper hard carbonate hardpan crust, discontinuously laminated and 0.5–2 m thick, gradually passing downward to a horizon characterized by carbonate nodules, tubes and columnar features affecting the gray mudstones and



Figure 3. Karst dissolution features: rillenkarren and kamenitza.

conglomerates of the bedrock. This horizon may be interrupted by erosional truncation surfaces overlaid by fluvial/colluvial deposits. The calcrete profile may be topped by modern soil, colluvial sediments or archaeological horizons.

3.2. Rocky pediment with tufa and/or calcrete

In the lower sector of the western side of the Misis Mountain Range, the surface may be topped by tufa deposits that may locally reach a wide extent. Thereby, in correspondence with the tufa deposits the fan surfaces are in general regularly smoothed, slightly inclined and, locally, they show horizontal or dome-like shapes separated by small depressions filled with red soils. Tufa are porous and contain remains of plant concretions and reworked biological clasts. The external surface is usually weathered with dissolution features where rillenkarren, kamenitza and alveoli are frequent (Figure 3) and carbonate re-deposition is present. The presence of these crusts favored the preservation of the original fan and pediment surface, in most cases limiting erosion to a single channel. The main outcrop is drawn as rocky pediment with tufa and/or calcrete.

3.3. Recent fluvial terraces

Recent and sub-modern fluvial terraces constitute surfaces placed 2–4 m above the level of the Ceyhan river, prevalently formed in the area of Misis and inside the large indenture of the Ceyhan river near the village of Abdioglu. Minor strips are preserved in the area of Misis. Recent terraces are prevalently composed of sandy silt and clayey silt. They are separated by the older fluvial deposits by means of a 3–4 m high scarp, not always visible due to intense reworking by agricultural activity.

3.4. Oldest fluvial terraces

On both sides of the Ceyhan river, the oldest fluvial surface gently degrades southward in the alluvial plain without a well-defined scarp, likely to be reworked by agricultural activities. The most elevated fluvial deposits are placed in the uppermost part of the plain, southward the calcrete terrace-like surface of the Adana Industrial Zone and surroundings of the Misis village. They constitute a wide terraced surface with a low slope gradient dissected by fluvial scarps. The deposits are mostly conglomerate which vary from massive to stratified, usually clast-supported with a grey-brown coarse-sandy matrix. Pebbles are sub-rounded, with decimetric maximum size and of variable but mostly carbonatic lithology.



Figure 4. Oxbow swamps due to recent variations in the fluvial channel pattern, near Kesik village (© 2016 DigitalGlobe, © 2016 GeoEye).

3.5. Fluvial–lacustrine and alluvial deposits with features of river avulsion/diversion

The alluvial plain is prevalently formed by silt deposits, locally passing to clayey and sandy sediments, as observed on the surface and in some vertical sections. This sediment distribution is related to variation of channel position (sandy layer) and formation of back swamp and oxbow lakes (clayey layer). The remote sensing analysis outlined the most recent variations in the fluvial channel pattern responsible for the complex stratigraphic architecture (Figures 4 and 5). The detected fluvial palaeotracas show river avulsions with consequent palaeomeanders locally forming oxbow swamps/lakes, abandoned channels and suites of concentric features generated by a progressive lateral meander migration.

3.6. Alluvial fans and slope deposits

The processes along the western slopes of the Misis Mountain Range led to the formation of extensive alluvial fans, partly coalescent, which border the eastern margin of the alluvial plain. These fans exhibit concave upward long profiles with low inclinations ($<10^\circ$) in the

distal part. In most cases, the post-depositional dissection processes appear limited only to a single channel.

3.7. Modern delta plain and coastal dunes

The modern delta plain is characterized by the eastward diversion of the Ceyhan across the Miocene dorsal of Karataş, thus determining the abandonment of the Dalyan river mouth. This diversion occurred in correspondence with a saddle to the north of the village of Bebeli. Since it is unlikely for a headward stream erosion in the southern side of the dorsal to prompt stream capture, the Ceyhan diversion might have happened when repetitive floods led the alluvial plain at the same elevation of the gap in the dorsal, thus favoring river run-off toward the east inside Ayash Bay. The Ceyhan diversion was initially believed to have occurred in the Middle Age, but recently it has been dated to about 3000–4000 yrs BP (Erol, 2003; Gürbüz, 1999) on the basis of the age of the archeological remains from a village standing on the sediments of an embryonic delta. The Ceyhan probably kept both directions (Dalyan mouth and Ayash bay) alternatively active, depending on the intensity of floods, variations in channel bed forms and lateral banks.



Figure 5. Evident progressive lateral meander migration near Esenler village (© 2016 DigitalGlobe, © 2016 GeoEye).

The river palaeotracés, identified on satellite imagery, show features of meander point-bar migration, indicating that the Ceyhan was very close to the Miocene hills potentially eroding the flanks at some points.

The Yumurtalik mouth was active until 1935 AD when the creation of a new diversion channel generated a southern sub-delta infilling a vast lagoon area to the east and south of the village of Adali. Part of



Figure 6. Traces of ancient tufa quarry.

the Agyatan lagoon is still visible today, and is delimited seaward by the coastal belt of Torbuk. Both the area proximal to the current active mouth and to that of 1935 show common features of deltaic morphology, with alternate small tidal flats and channels, lagoons, marshy areas and occasionally flooded lowlands.

A wide belt of active linear dunes developed along the coast facing the beach shore and pass inland to hummocky as well as locally parabolic dunes. Marshy areas punctuate the intra-dune depressions. The limit between the dune belt and the lagoon is sharp and rectilinear. In correspondence with the modern mouth, the interplay between delta progradation, growing dunes and beach shores nourished by littoral drifts has generated small and elongated shallow water areas separated by the sea.

On the western side, near the Akyatan lagoon, a well-developed dune belt passes inland from active dunes to stabilized deposits as far as deposits reworked by intense agricultural activity. The northern and western sides of the lagoon are characterized by marshy and lacustrine deposits, while on the eastern side alluvial fan deposits separate the lagoon from the Karats dorsal.

3.8. Anthropogenic elements

In addition to urbanized areas and intense agricultural practices reworking the entire plain, quarries have left important traces. Two modern quarries are present in the northern part of the Misis Mountain Range, and many traces of ancient exploitation are frequent on the paleosurfaces represented by the weathered top of tufa deposits covering the alluvial fans and slope deposits. The biggest traces usually form large quadrangular area, the fronts of excavation show the typical parallel-piped surfaces of extraction with small fissures produced for block cutting. This picture suggests that most of the quarries were used to produce elements for building constructions. However, there is rarer evidence of exploitation for producing other types of artifacts possibly aimed at productive activity (Figure 6). In some cases, abundant archeological remains (i.e. pottery, bricks, and tiles) are associated with quarries, an occurrence which should be explored in detail in order to better clarify the significance of exploitation and its chronology.

4. Conclusions

The geomorphological characteristics of the lower plain of the Ceyhan river have been defined, thanks to three field work campaigns and remote sensing analysis, augmented with historical documents and modern data available for the surrounding regions. The results have brought to light features comparable with other sectors of the Çukurova plain and other coastal areas in Mediterranean Turkey (e.g. Alphan, 2005; Brückner, 1997; Brückner, Müllenhoff, Handl, & van der Borg, 2002; Ekericin, 2007). All the landforms were developed under the forces of climatic and environmental variations that occurred from the Middle Pleistocene to the Middle Holocene (Aksu et al., 1992, 2005), when man began to effectively shape the landscape (Bintliff, 2002; Casana, 2008). Currently, we are unable to define the phases of history for the Ceyhan plain and it is only possible to draft a general framework. During field surveys and remote sensing analysis, many remains were found of archaeological settlements and traces of human exploitation of the environment. Owing to the heavy pressure of agriculture on this plain and to the strong link between ancient settlements and the river crossing the plain, further work would be necessary to outline a detailed picture of river evolution and settlement distribution.

This map may provide a basis to effectively plan further activities, i.e. shallow trenches, boreholes and near-surface geophysical prospecting, designed to gain direct evidence of natural and anthropogenic events, with a particular focus on ancient settlements.

Software

ENVI[®] was used to create pan-sharpened multispectral Landsat ETM+ imagery. The ASTER DEM (for terrestrial areas) and GEBCO DEM (bathymetry) used for the background map and the auxiliary maps were processed in Global Mapper[®] 10. Vector data management and final layout were performed using ESRI[®] ArcMap 10.2.1.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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