

SCIENCE

Geomorphology of the El Alamein Battlefield (Southern Front, Egypt)

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This map outlines the main processes and related landforms of the stretch of the Western Desert from Deir El Munassib to El Taqa Plateau, south of El Alamein (Egypt). Freely available digital elevation data derived from the Shuttle Radar Topography Mission, image processing of the *Advanced Spaceborne Thermal Emission and Reflection Radiometer* and field surveys have led to the geomorphological map at 1:40,000 scale. Landforms constitute the result of the complex interplay of gravitational, aeolian, coastal and fluvial processes strongly influenced by geological structure. Particular attention was devoted to the recognition, identification and mapping of military remains dating to 1942, which occur all over the study area.

Keywords: desert geomorphology; Western desert; El Alamein; Egypt

1. Introduction

The El Alamein Battlefield is located in Egypt, as part of the Western Desert, about 250 km west of Cairo (Figure 1); the study area is characterized by arid to hyper arid climate (Parson & Abrahams, 2009) and contains a number of typical desert morphologies (*hamada*, *serir*, *wadi-fan* systems, etc.) widespread over the entire study area. A number of military remains dating to the famous Battle of El Alamein have been surveyed and mapped. Three main battles took place at El Alamein in 1942 and changed the outcome of World War 2 (WW2; Figure 2). The geomorphological map of the southern sector of the El Alamein Battlefield (see Main map) is the result of the analysis of aerial photographs and satellite images, digital terrain model (DTM) processing and field surveying in the area affected by war events.

2. Study area

The study area encompasses the southern sector of the El Alamein Battlefield (northwestern edge: 30°37'54"N, southeastern edge: 28°48'13"E), about 3600 km², located roughly 100 km west of Alexandria.

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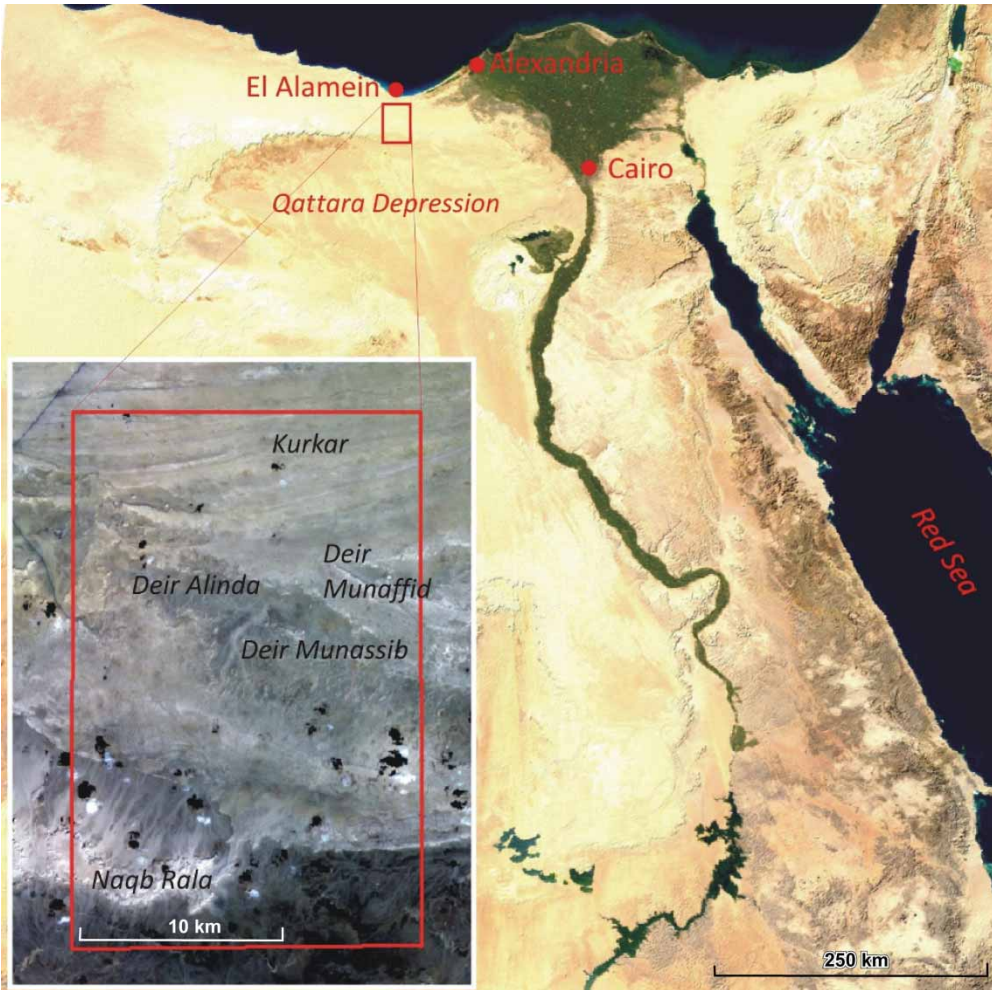


Figure 1. Study area. The red rectangle indicates the mapped area.

Coastal lagoons, known as *sabkhas*, characterized by evaporite-carbonate deposits occur in the northern sector of the study area, along the Mediterranean coast, where the development of a number of tourist resorts has severely altered the natural environment. Moving southward, a series of eight coast-parallel ridges, locally called *kurkar*, form a smooth undulated surface (Embabi, 2004). Their elevations range from tens to a hundred meters and may represent the palaeostructure of the Nile delta. Farther to the south, four main aeolian depressions (Deir El Qattara, Deir Alinda, Deir El Munassib, Deir El Munafid) and a number of minor ones are present. They are developed in east-west direction and the depth of the depressions range from a few meters up to 30 m. They have developed on a near horizontal structural surface and are carved mainly in limestone rocks. Southward, beyond a flat, horizontal carbonate plateau (Point 105 in the Main Map), a wadi-fan system is developed (*bahada*). The carbonate plateau is separated from the northern plateau by a 1–2 m scarp. Alluvial deposits are derived from at least seven limestone layers (El Taqa plateau), which are located in the southernmost sector of the study area. This area is characterized by *mesas* and *cuestas* (Figure 3) that decrease in elevation toward the El Qattara Depression, whose maximum depth is –165 m (Embabi, 2004).

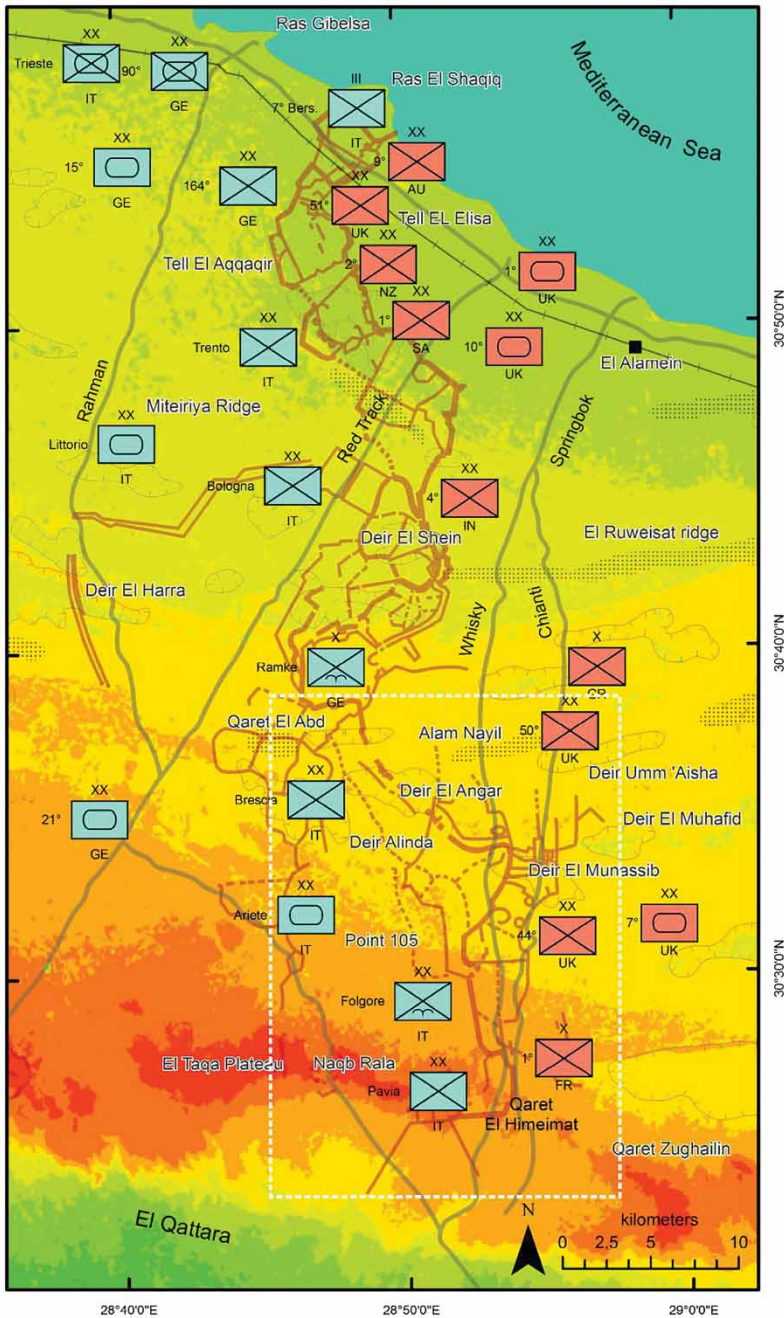


Figure 2. Military map of the El Alamein's battlefield before the third and final battle of El Alamein (23 October 1942). The white rectangle indicates the surveyed area. Red units belong to Allied Forces, blue units to Axis forces. Legend: IT, Italy; GE, Germany; UK, United Kingdom; IN, India; SA, South Africa; AU, Australia; NZ, New Zealand; FR, France; XX, Division; X, Brigade; II, Regiment; Crossed box, infantry unit; ellipse, armored unit; crossed box with wings, airborne unit; crossed box with ellipse, mechanized unit; Brown lines, minefields; gray lines, tracks; Green areas, low elevation; red areas, high elevation; Dotted area, main ridge.



Figure 3. Mesas and cuestas on the El Taqa Plateau, bordering the southern side of the battlefield. The escarpments are approximately 30 m high.

The geological background of the area is provided by the 1:250,000 Geological Map of Egypt, sheet n. 20 (Rushdi, 1990). The stratigraphic sequence occurring in the study area spans from Early Miocene to Pleistocene. The southern sector, at the border with the El Qattara Depression, is characterized by an Early Miocene clastic sequence with alternating sandstones, marlstones and limestone rocks (*Moghra Formation*; El-Barkooky et al., 2009). The Moghra Formation is represented on the map by *terrigenous bedrock*; when the sediments form a shallow cover on the rock surface, 1–2 m deep, they are shown as *shallow terrigenous bedrock*. In the central part of the map area, a Pliocene dolomitic carbonate sequence occurs (*Marmarica Formation*), while the *kurkar* area is characterized by Pliocene-Pleistocene limestones (*El Hagif* and *Alessandria Formations*; Rushdi, 1990; Stanley & Hamza, 1992). These two latter formations are reported either as *carbonate bedrock* or *shallow carbonate bedrock*, when covered by discontinuous and shallow debris deposits. The El Alamein battlefield is relatively flat, with horizontal or slightly inclined sedimentary bedrock. Relief is lower than 300 m and limited to the southern sector.

The arid and hyper arid climate is characterized by gentle and dry winters and dry and very hot summers. The hottest months are July and August. Temperatures range during the whole year from 0°C to 40°C. The southernmost sector of Western Desert is considered one of the driest regions of the world (Kehl & Bornkamm, 1993); here the decrease in rainfall is accompanied by increases in temperature and evapotranspiration in a North to South direction. Mean rainfall is 200 mm/year along the coast and decreases significantly in the Naqb Rala area (50 mm/year). Dominant winds are from the northwest.

3. Material and methods

Satellite image processing and photo-interpretation, regional DTM analysis and geomorphological field surveys were carried out in the Southern sector of the El Alamein battlefront. The terrain analyses has been performed using Google Earth imagery (SPOT, Geo-Eye-1 and Quickbird in the surveyed area), two *Advanced Spaceborne Thermal Emission and Reflection Radiometer* (ASTER) L1B scenes belonging to the same frame acquired on 10 October 2003 (resolution of 15 m/pixel and 30 m/pixel for VNIR and SWIR bands, respectively) and a DTM derived from the Shuttle Radar Topography Mission (SRTM-3) survey (90 m spatial resolution). The SRTM DTM has been studied using shaded relief, *aspect* and *slope* visualizations. ASTER imagery were orthorectified using the SRTM DTM and corrected both for the effects of *cross-talk* (signal leakage from ASTER band 4 into adjacent bands 5 and 9; Iwasaki & Tonooka, 2005) and *atmosphere differential wavelength scattering*. In particular, the atmospheric correction has been implemented converting the VNIR and SWIR bands from at-sensor radiance into surface reflectance using a desert aerosol model in the ENVI-FLAASH module, which incorporates the MODTRAN4 radiation transfer code (Cooley et al., 2002). This correction enabled us to rely on ASTER data for relating different surface compositions with specific morphologies and/or diverse desert pavements. For example within the *deir* depressions, the silico-clastic Moghra Formation, at the base of the stratigraphic sequence, crops out surrounded by the younger carbonate series; *hamada* and *serir* spectral signatures are characterized by a different depth of the carbonate absorption peak (better defined in the *hamada* terrain as it is composed of large carbonate pebbles and boulders); flash floods deposits (*bahadas*) and *wadi-fans* are often well defined by a different spectral response with respect to surroundings areas.

For the interpretation of surface composition we favored the 7-3-1 Red Green Blue (RGB) color composites and the 2/1, 7/8 and 7/6 band ratios. This enabled us to highlight: (i) the Fe^{3+} absorption peak centered at ASTER band 1 and the reddening effect typical of the desert varnish well developed at the surface of outcropping rocks of the Moghra Formation and *serir* pavements; (ii) the Al-OH absorption peak at ASTER band 6 which is typical of the clay minerals associated with the Moghra Formation and many *deir* floors, (iii) the absorption of the CO_3^{2-} ion which is located at ASTER band 8 and shows a distinct behavior for the limestones and dolostones of the outcropping rocks and *hamadas* of the Plio-Pleistocene carbonate sequence (Marmarica, El Hagif and Alessandria Formations). In addition, a Principal Component Analysis has been also performed and the color composite RGB PC3-PC2-PC1 has been used for the evaluation of surface color variegation because the first three principal components load most of the variance of the original data-set.

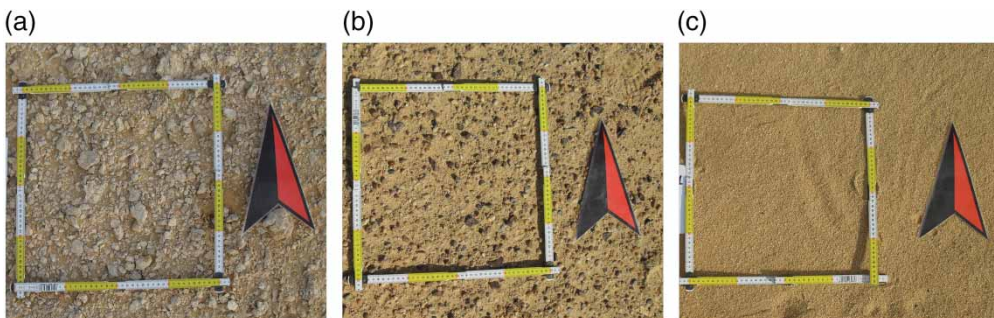


Figure 4. North-oriented Ground Control Points showing the different surface characteristics: (a) *hamada* ground; (b) *serir* ground; (c) sandy ground.

Remote sensing interpretation has been validated and refined through field surveying (Figure 4). Thirty-five GCP (*Ground Control Points*) were collected using the following field protocol: (1) positioning a north-oriented 40 cm square, using a folding ruler; (2) photographing the desert surface (digital images, vertical close up and oblique views); (3) collecting sediment/rock sample and (4) global positioning system receiver coordinates.

The geomorphological map has been organized according to a morphogenetic classification of landforms. Deposits and landforms were organized according to the prevailing geomorphological process; in particular we considered fluvial, gravitational, aeolian and structural landforms.

4. Main landforms

4.1. Coastal ridges (*kurkars*)

Kurkars are well-developed on the coastal plain to the west of Alexandria. Their origin remains a matter of debate. A number of authors support a polygenetic origin (Butzer, 1960; El-Asmar, 1994a, 1994b, 2000; Shukri, Philip, & Said, 1956; Stanley & Hamza, 1992). *Kurkars* develop by wave action and local currents during transgressions. Shore processes created submerged parallel bars. During regressive phases, the submerged bars were subsequently exposed to subaerial processes, forming littoral bars through aeolian processes; subsequent pedogenesis and weathering processes contributed to their present form. *Kurkar* topography is characterized by slight discontinuous relief. Butzer (1960), Shukri et al. (1956) and Wali et al. (1994) suggest that the most

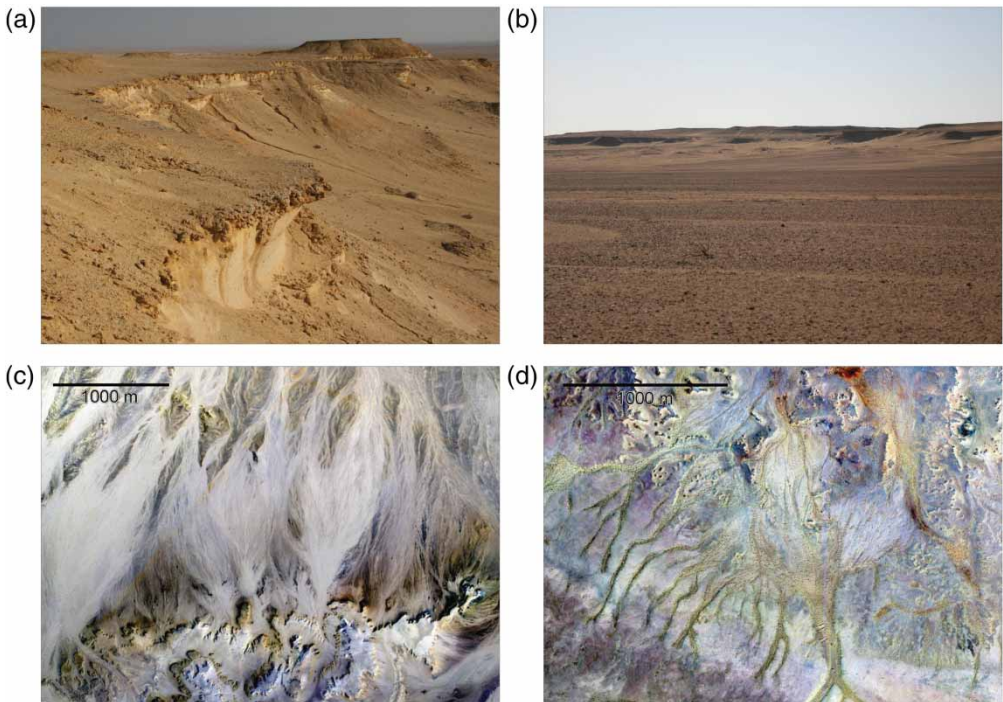


Figure 5. Examples of landforms in the study area: (a) escarpments at the front of the *cuestas* in Naqb Rala (El Taqa Plateau); (b) the floor of the Deir El Munassib Depression; peripheral scarps can be seen on the horizon; (c) wadi-fan system: the sediments are transported from South to North, forming coalescent cones; (d) network of wadis along the border of Point 105 (Quota 105).

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ancient *kurkars* are Pleistocene in age, approximately 950 ka. Eight ridges occur, each separated by longitudinal depressions (Butzer, 1960).

DEM (SRTM) data processing and the georeferencing of topographical maps at 1:250,000 and 1:100,000 served to highlight the occurrence of *kurkars* in the northern sector of the study area.

4.2. *Deirs*

Deir is a flat depression in a sub-horizontal rocky plateau. Embabi (2004) suggested that these depressions can be subdivided according to their size, ranging from centimeters to hundreds of kilometers. In particular, the author suggested that minor depressions represent the first step in the evolution of a *deir*, while the larger ones are the result of coalescence processes among several *deirs* (Figure 5).

Four major depressions have been recognized in the study area, up to 30 km in size: Deir El Munafid, Deir El Munassid, Deir Alinda, Deir El Angar.

Generally, *deirs* are covered by alluvial and aeolian deposits, while the surroundings are composed by rocky outcrops. Their genesis is mainly due to aeolian processes (Embabi, 2004) and subordinately by karstic solution and salt weathering.

4.3. *Limestone structural surface*

A broad exposure of Miocene limestone crops out at Point 105. Slopes up to 5 m in height, border the southern and eastern front. The surface is cut by isolated wadis, from 10 to 50 meters in size and up to 3 meters deep. The contact with alluvial deposits and prominent cliffs is usually covered by rockfall, representing successive generations of gravitational collapses.

4.4. *Wadi-fans*

Wadi-fans are well developed in the study area. Because of the extreme aridity, the drainage pattern is formed by intermittent streams on alluvial fan surfaces and is composed of braiding or ephemeral channels. During intense rains the channels may be filled with sediments under turbulent flow (Fairbridge, 1968). Deposition in a *wadi* is rapid because of the sudden loss of stream velocity and seepage of water into the highly porous underlying sediments. As a result, *wadi* deposits are typically composed of poorly sorted gravels and sands. Subsequent to deposition, these sediments are commonly reworked by aeolian processes. Various *wadi* depositional morphologies, as ‘*wadi* fills’ or *wadi* fans, developed close to the slope, and *bahadas* (Mo’Awad, 2003) or ‘piedmont plains’ (Shata, 1971) have been found. The piedmont plains morphology are broad slopes of detrital alluvial outwash, usually composed of coalescing alluvial fans, whereas *bahadas* are aggradational features, formed during or immediately following flash floods.

In the study area, *bahadas* are mainly developed along south exposed slopes, toward El Qattara depression. Intense rainfall commonly creates temporary ponds or small lakes. Accumulation of fine sediments in these small lakes form layers of low infiltration and serve as confining layers above subsurface water-bearing units (Embabi, 2004).

4.5. *Serir*

Serirs are deflation surfaces formed by aeolian processes that winnow fines from the alluvial deposits. They act selectively, removing fine particles (silt and sand) while gravels, pebbles

and heavy rocky fragments remain as a surface armor. This coarse sediment cover protects the underlying sediments and bedrock to the extent that no additional fines can be removed and the process ends. Pebbles are often covered by desert varnish.

4.6. Hamada

Hamada, or rocky plain surface, are associated with surfaces formed on the limestone plateau. A *hamada* is a desert plateau where deflation has removed the fine-grained surface materials and left behind a surface of sand-scoured bedrock with or without a veneer of pebbles or boulders (Gautier, 1935). This kind of morphology is mainly due to processes that remove smaller detritus, caused by wind action and precipitation. Consequently, large size detritus remains *in situ*, and are observed to blanket the landscape. In the study area *hamadas* are associated with rocky outcrops.

4.7. Military features

Because the study area is located within the southernmost sector of the El Alamein battlefield, physical remnants of military activity are found throughout the area. The defense system developed along the front is strongly influenced by topographical and geomorphological features, even the most minor element of relief is of critical importance in a desert war. Emplacements, such as foxholes, entrenchments, sangars (temporary fortified positions with a breastwork constructed of



Figure 6. Examples of military remains along the Southernmost sector of the battlefield: (a) the Rommel Track (also known as Red Track), built by the British Army before the war; (b) the entrance to underground fortified chambers at Kaponga Box, which is a British fortress at Qaret El Abd; (c) an Italian foxhole at Point 105 (Quota 105); (d) an Italian observation post along the Southern front to El Qattara Depression.

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stones), artillery emplacements, depots, command posts, etc. (Figure 6) have been mapped. Emplacements are globally heterogeneous in shape, since their structure does not follow a particular plan. They consist mainly of several deep holes cut in the rock surface or Quaternary deposits, very often reinforced with low stonewalls. The connections between emplacements were made by a network of dirt roads or trails. The most important ones are reported in the Main map. The military emplacements are part of a historical GIS forming the framework of the El Alamein Project. About 1000, of 20,000, have been surveyed and photographed, some 300 have been dug and restored. All the geographical features have been related to historical maps and war journals in order to recognize the military units occupying the different sites. A military map of the El Alamein Battlefield will be published.

5. Conclusions

The geomorphological map of the El Alamein Battlefield represents the first attempt to study this key-area in the history of WW2. The study of the geomorphological features and the surveying of military installations allowed us to map the main natural and anthropogenic morphological elements of the area. This work is part of wider military geography research on the El Alamein battlefield under the organization of the El Alamein Project (Bondesan, 2012). The geomorphological framework given by the map will form the fundamental basis for the reconstruction of the WW2 battlefield.

Software

All the image processing was performed using ENVI. Esri ArcGIS 10.0 was used for georeferencing, data-integration, mapping and editing of the final geomorphological map.

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GEOMORPHOLOGICAL MAP OF THE EL ALAMEIN BATTLEFIELD (SOUTHERN FRONT)

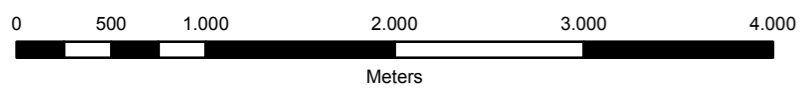


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GEOMORPHOLOGICAL MAP OF THE EL ALAMEIN BATTLEFIELD (SOUTHERN FRONT) WESTERN DESERT, EGYPT

Scale 1:40.000



Spatial reference: WGS 1984 (UTM, Zone 35 N)
Contour interval: 25 meters

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LOCATION MAP



Source: US National Park Service,
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LEGEND

- Minefield (1942)
- Desert track
- Military emplacement
- Cliff < 5 m
- 5 m ≤ cliff ≤ 10 m
- Cliff > 10 m
- Incised wadi
- Kurkar lineament
- Depression edge
- Alluvial deposit (more clayey)
- Alluvial deposit (less clayey)
- Aeolian deposit
- Mixed eolian, alluvial and colluvial deposit
- Terrigenous bedrock
- Shallow terrigenous bedrock
- Carbonate bedrock (mainly limestone)
- Shallow carbonate bedrock (mainly limestone)
- Wadi-fan system
- Serir
- Hamada
- Mesa surface - lower terrace
- Mesa surface - higher terrace
- Discontinuous horizontal bed of hard rock
- Interkurkar depression
- Contour line

