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Geomorphological Map of the Tadrart Acacus Massif and the Erg Uan Kasa (Libyan Central Sahara)

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The Libyan central Sahara

Geomorphological studies in the central Sahara originate since the wide field experience gained in the last decades (1990-today) of geoarchaeological research carried out by the team of University of Milan in the framework of the Italian-Libyan Archaeological Mission in the Acacus and Messak (Central Sahara) of Sapienza University of Rome and the Libyan Department of Archaeology. The Libyan central Sahara is well known for its archaeological treasures, together with the exceptional artistic, which led UNESCO to insert the rock art sites of the Tadrart Acacus in the World Heritage.

The Map

The map (scale 1:250,000) covers two different physiographic elements of the landscape of the central Sahara: a massif and a dune field. These two features appear rather different, but we decided to represent them together in the map because they belong to same (palaeo-)hydrological system. In fact, during the humid phases of the Tertiary and Quaternary, the massif and the lowlands occupied by the dune field were connected by a huge drainage system, which existence is today confirmed by extensive fluvatile deposits and palaeochannels. In the map, we highlight the importance of landforms and surface deposits typical of the extant arid environment, as much as feature testifying for former humid periods.

The climate is hyperarid

Mean annual T: 22/25°C

Mean precipitation: 0-10 mm

The Tadrart Acacus Massif is a sandstone massif located in south-western Libya, in the Fezzan region, well inside the hyperarid belt of the Sahara desert, between 26° and 24° latitude N. It covers an area of c. 5000 km² with a maximum elevation of c. 1300 m a.s.l. in the western part. The mountain system consists of a monocline, which is dissected by a fossil drainage network, whose pattern is controlled by the tectonic structure. A sharp scarp delimits the massif towards the West, while to the East it progressively passes through a pediment to the Erg Uan Kasa. The latter is a 4500 km² wide sand sea, mostly constituted by NW-SE oriented alignments of complex dunes, located within the wide depression of Tin Merzuqa, between the Tadrart Acacus Massif and the Messak Plateau. The dune ridges are separated by wide and flat interdune corridors, whose bottom is occupied by thin sand covers becoming thicker toward East.

Simplified geological map

Geologically, this region belongs to the western fringe of the Murzuq, whose base, mainly composed of Palaeozoic shales, sandstone, marls, and, less frequently, limestone, lies upon the intrusive formation of the Tassili. The Tadrart Acacus Massif consists of Lower to Middle Silurian shales (Tanezzuft Fm.), apparently conformably overlying Upper Silurian and Lower Devonian sandstones (Acacus and Tadrart Fms.). In the Tin Merzuqa depression some NS oriented cuestas, cut into Carboniferous limestone, outcrop. The Late Quaternary deposits consist of fluvial sand and silt and loamy-clay formed in lacustrine to shallow water environments during wet phases; further, during arid environmental conditions sand sheets and dunes were formed thanks to enhanced wind activity.

Structural and residual forms

The main structural pattern of the Tadrart Acacus and adjoining areas consists of monocline relieves, intercalated to flat areas. The cuestras are composed of Palaeozoic sedimentary rocks that in the Tadrart Acacus areas are cut by a dendritic fluvial network. Satellite imagery and published geological maps highlight the occurrence of a major inactive fault cutting the Tadrart Acacus massive from north to south, while a system of parallel inactive faults is SW-NE oriented, roughly corresponding to the main direction of the fluvial net.

Structural and residual forms

The present-day shape of the massif was determined by the onset of etchplanation processes, which is dated presumably to the Paleogene under humid and warm climatic conditions. A thick lateritic soil originated in this phase was then almost completely removed during subsequent erosional events and only few paleosol strips are at present still evident in the Tadrart Acacus.

Due to a moderate tectonic uplifting and climatic oscillation playing since the Neogene, erosion shaped the massif in a series of structural terraces corresponding to sub-horizontal strata. The desert pavement of the terraces and of the most elevated, flat parts of the massif corresponds to a hamada surface, whose clasts, as much as most of the exposed rock surfaces of the region, are coated by a continuous layer of dark, Mn-rich rock varnish.

Slope forms and deposits

Toward the West, the Tadrart Acacus Massif is delimited by an uninterrupted escarpment up to 400 m high, which consists of a series of ancestral hanging valleys. At the base of the scarp a talus ramp is present, where sandstone blocks accumulated; the foot of the slope deposits is covered by the Holocene alluvial sediments of the Wadi Tanezzuft.

Along the wadis of the Tadrart Acacus, several mass-wasting deposits, consisting of angular sandstone blocks, are present. They were interpreted as large landslides affecting the cliffs of the wadis and triggered by thermoclastic processes under arid environmental conditions.

Fluvial forms and deposits

In the Tadrart Acacus area a moderately continuing tectonic uplift allowed linear erosion to dissect the dense dendritic net of wadis, which is evident in satellite imagery. The wadi banks are deeply excavated in the sandstone bedrock, becoming upstream narrow and meandering canyons with vertical cliffs; whereas in the lower part of their course, the wadi bottom is generally flat and filled by fluvial sediments, covered by aeolian sand. The excavation of deep valleys was triggered by the occurrence of major inactive faults and fractures cutting the bedrock, while the original width of the valleys has been enlarged by the backwasting of scarps.

Fluvial forms and deposits

During wetter phases, turbulently rushing water carved along the wadis a complex systems of longitudinal grooves, pools and deep potholes distributed in the upper part of canyons. The largest of these potholes, which occasionally are in part excavated in the sandy bed of a wadi, are locally called gueltas or agelma in the Tuareg language. They consist of small water reservoirs recharged by occasional rainfall and persisting for few month.

Fluvial forms and deposits

The glacia between the Tadrart Acacus and the Messak plateau displays more evidence of fluvial activity. The area is marked by ephemeral streams descending into the Tin Merzuqa depression; further, some scarps produced by fluvial erosion are occasionally evident in satellite imagery as much as in the field. At several localities, the palaeochannels cut the glacia and the main cuestas and are generally W-E oriented, while in the central part of the Tin Merzuqa depression a discontinuous N-S oriented cut emerges between the dunes. Palaeochannels are the evidence for a very ancient drainage system that dissected the glacia from north to south well before the formation of the sand sea. Moreover, transversal E-W cuts may be related to several tributary flowing from the Tadrart Acacus and Messak massifs into the depression of Tin Merzuqa.

Aeolian forms and deposits

The Erg Uan Kasa is the most evident aeolian landform of the map. It formed along the Tin Merzuqa depression, which is a flat glacia developed between the cuestas cut into the Carboniferous limestone and sandstone strata. The dunes of the erg are organized as parallel ridges, generally NW-SE oriented and separated by wide flat basins, sometimes crossed by transverse sand crests. The sandy cover on the basins' bottom increases toward East, and at the eastern margin of the dunefield a discontinuous sand sheet dotted by single or grouped barchans is present.

Aeolian forms and deposits

The morphology of the dune ridges is quite complex and they cannot be interpreted simply as a series of multiple or dendritic linear dunes. They represent complex sand buildings, which are formed by a multiple network of linear dunes connecting star domes. Complex sand ridges are separated by flat interdune basins, up to some km wide; the most depressed part of the basins is generally poorly covered by sand and a fine-texturedserir outcrops.

Aeolian forms and deposits

Most of the aeolian dunes and sand sheets seem being active, due to the winds that characterize the hyperarid climate of the region. Few large accumulations of sand, strongly weathered and on the way to be dismantled, sometimes come out form the sand; these represent dunes accumulated in the Pleistocene and strongly weathered under interglacial wet and warm conditions.

Aeolian forms and deposits

Along the main wadis of the Tadrart Acacus Massif and at its margins some minor aeolian forms are present; most of them are very small and thus difficult to be represented at the chosen scale. They most consist of sand sheets formed on the flat bed of some wadis, discontinuous fields of small barchans, climbing dunes accumulated against the wadi banks, and nebkhas developed around shrubs in the most vegetated parts of the valleys. Only at the southern margin of the massif, in the Takarkori region, a larger aeolian feature is present. In fact, in a wide depression at the border between Libya and Algeria a significant accumulation of sand exists (a sand sheet dotted by small barchans), and it is on the way to cover the remains of a palaeolake. Moreover, at the northern margin of the Takarkori depression a large and complex dune, possibly originating by the coalescence of several star dunes, exists.

Forms and deposits related to the high stand of the ground water

Lacustrine sediments can be identified on the basis of visual interpretation of satellite imageries: they are represented by areas with high reflectance, greyish to light bluish in color, and brighter than sand. In spite of this, the distribution and morphology of lake sediments were checked in the field, because the outcrops of Mesozoic limestone display almost the same reflectance and colors.

Forms and deposits related to the high stand of the ground water

In the field, lake deposits are made of calcium carbonate-rich mud and are mainly located close to the largest dunes systems; they cover the bottom of the corridors or were cut by wind erosion forming terraces and yardangs. Sediments were dated (on the basis of a robust ^{14}C chronology and of their relation with archaeological indicators) to the Pleistocene and the Holocene. The latter are in many cases unconsolidated and cover the most depressed parts of the basins; in few cases, Holocene carbonates occur as aerodynamically shaped yardangs. On the other hand, Pleistocene lacustrine deposits are represented by massive carbonate terraces, and iron crusts, possibly related to bog iron. Lacustrine sediments have to be attributed to piezometric lakes, which formation was triggered by the outcrop of surface water reservoirs recharged by intense monsoonal rainfalls during Pleistocene interglacials and in the African Humid Period.

Forms and deposits related to the high stand of the ground water

Satellite imagery also highlights the occurrence, between the Tadrart Acacus Massif and the Erg Uan Kasa, of some bright bluish spots, which in the field correspond to thick silty to clay, inorganic crusts, displaying a fining upward sedimentary trend. These surfaces do not represent marsh deposits, but can be interpreted as desiccation crusts: the small depression were occasionally/seasonally flooded by ephemeral streams and the desiccation led to the deposition of fine-grained sediments. Desiccation crusts are sometime present also along the largest wadis that cut the Tadrart Acacus Massif.

Spring tufa in the Tadrart Acacus

Along the wadi banks in the inner parts of the Tadrart Acacus Massif, at an elevation ranging from 900 to 1000 m a.s.l., calcareous tufa were identified. Outcrops of this kind of rock were found within rock shelters, along vertical fractures inside relict solutional tunnels, and on vertical cliffs; they are related to the horizontal boundary between sandstone and thin, impermeable beds of shale or fine-grained sandstone beneath. In the central part of the Tadrart Acacus, tufa deposits occur as thin laminated crusts at the floors of the rockshelters and belong to the pool and barrage types; whereas, in the upper reach of the wadis up to few tens of meter long alignments of massive flowstone line vertical walls. In the latter case stalactites may be 2 m long.

Spring tufa in the Tadrart Acacus

The microscopic properties of tufa were discussed by Carrara et al. (1998) and Cremaschi et al. (2010); while several U/Th and radiocarbon dating permitted to attribute their deposition to the Early Holocene (Cremaschi et al., 2010). Due to the topographic and geologic position of tufa and their sedimentological characteristics, we can define them as spring tufa and their occurrence indicates the position of ancient springs that were active during humid phases.

Solutional features

Underground solutional processes, reaching some hundred meters of depth, are well expressed in the Tadrart Acacus area, but they could not be represented in the map. They consist of vertical and horizontal tubes, tunnels, weathering pits, large caves, pits etching the bedding planes on steep slopes, rock arches, towers, and pillars. The ruiniform landscape at the eastern entrance of the massif, which consists of a wide assemblage of towers and pillars, well represents the effects of solutional processes on sandstone. Cavernous weathering is particularly well developed along the banks of the main wadis, that are dotted by rock shelters, alcoves and caves formed in massive sandstone units by undersapping along bedding planes at the contact between the sandstones beds and the shales. Finally, solutional micro-features are also present, mostly represented by clustered potholes and shallow depressions on flat horizontal surfaces.

Solutional features

In the Tadrart Acacus peculiar Fe-bearing mineral deposits, whose formation is related to the occurrence of a deep underground network of cavities, are worthy of notice. Under a tropical climate solutional processes were able to reach the ferruginous sandstone beds of the Tadrart and Acacus Fms., and contributed to the chemical mobilization and leaching of iron. Due to large water availability (possibly reaching the water saturation of the whole mountain), Fe-rich solutions migrated within the discontinuities of the bedrock, precipitating as iron minerals within caves and fractures. Iron mineralization consists of banded iron speleothems inside large caves, mammilate stromatolite-like crusts along fractures, and as Fe-cements within gravel bodies at the mouth of the underground drainage network.

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