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Large collapse sinkholes, old and new, in the Obruk Plateau, Turkey

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Abstract: Obruks are large collapse sinkholes in a low limestone plateau within the Konya Basin of central Turkey. There are numerous old obruks, in various states of degradation, and also 21 that have formed within the last 40 years. They appear to have hypogenic origins, with the new obruks induced by drainage changes.

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Figure 1: *Inoba Obruk, the sinkhole that opened overnight to a depth of 35m in what had been level ground.*

In the heart of peninsular Turkey (Anatolia), the Konya Basin is a sweeping semi-desert terrain surrounded by hills and mountains. Salt Lake (Tuz Golu) lies within the northern half of the basin, and the southern half is floored by the dry Konya Plain. Between the two depressions lies the Obruk Plateau (Obruk Yaylasi, or Sinkhole Plateau), which is roughly 50km in diameter. The Basin's minimal water resources are dominated by run-off from the Taurus Mountains along its southern margin. Most of its internal drainage is underground through multiple thick limestones, passing beneath the Konya Plain, then beneath the Obruk Plateau. Groundwater emerges at springs and seepages beneath and around the shallow Salt Lake, which has no surface outlet because its input flows are matched by losses to evaporation.

Figure 2: *The seventh new sinkhole at Seyithaci was only a metre deep but broke the road into the village.*

The Obruk Plateau takes its name from the dozens of notably large, old, collapse and caprock sinkholes that provide the most conspicuous landmarks within a rather mundane terrain (Fig.1). Relatively recently their numbers have increased with the formation of a suite of new sinkholes. This short report derives from the writer's brief visit to the Konya Basin, fortuitously timed soon after a new collapse event in the village of Seyithaci (Fig.2). Except for the collapses that post-date their writing, the obruks are well documented by Doğan and Yilmaz (2011), and genesis of the old obruks is described by Bayari *et al.* (2009). These are impressive sinkholes, and they deserve to be more widely known.

Whereas some geomorphologists might describe many of these landforms as dolines, the term is hardly appropriate for some of the deep, vertical-sided features that have formed recently. Therefore the term sinkhole is used intentionally throughout this report, because it encompasses all of the various morphologies covered by modern North American parlance and is the best translation of the local Turkish name, obruk.

Figure 3: *Location of the Obruk Plateau in central Anatolia; the rectangular frame marks the area shown in Figure 21.*

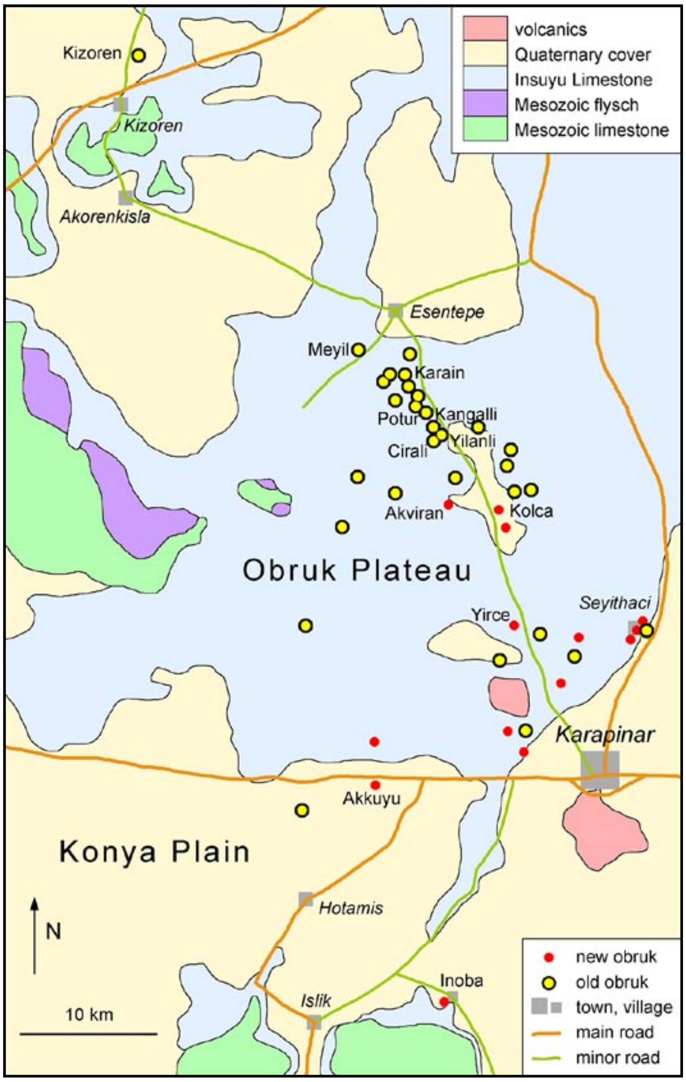

Figure 4: *Simplified geology of the Obruk Plateau, with locations of some of the main old and new obruks. The position within the Konya Basin is shown in Figure 21. (Outcrops after mapping by Turkish Geological Survey.)*

The Obruk Plateau

The plateau is no great dramatic feature. Most of it stands at altitudes around 1100m, less than 100m above the Konya Plain and 200m above Salt Lake. Nearly all of its margins are gentle slopes, the exception being a modest fault-line scarp along its southeastern edge past Seyithaci village (Fig.4). The bulk of the plateau is formed of Neogene Insuyu Limestone, which is up to 200m thick and lies close to horizontal. Parts of the limestone are capped by Pleistocene and Holocene alluvial sands, clays and gravels that locally reach about 100m in thickness and also extend under the Konya Plain. The Insuyu Limestone is thinly bedded and impure with multiple clastic horizons; karst features within its terrain are minimal, except that it contains most of the visible parts of the giant sinkholes. It overlies Mesozoic carbonates that are poorly exposed but are strong rocks, more likely to be significantly cavernous than their Neogene cover. Upper Cretaceous flysch deposits (turbidite sequences of sandstone and clay) intervene between the two limestones, but probably only beneath the western sector of the plateau. Vents of Pleistocene volcanoes breach the limestone around Karapinar, and the lakes of Meke and Aci, east of the city, are in volcanic craters, not in karst features.

Figure 5: *GoogleEarth image of the main group of old obruks near the centre of the plateau, including Meyil and Cirali that are distinguished by their dark lakes.*

Gently rolling and rather featureless, the Obruk Plateau has a scatter of villages whose resident farmers survive on the products of sheep-grazing and vast fields of low-yield wheat. Annual rainfall of about 300mm includes a significant amount that falls as snow; evapotranspiration is four times that figure, so the land is seriously dry through the long hot summers. Irrigation is expensive, and is more widespread on the surrounding lowlands, notably around the town of Karapinar, southeast of the plateau.

Figure 6: *The lake in Kizoren Obruk is around 120m deep.*

Figure 7: *Meyil Obruk has a shallow lake on its floor.*

Figure 8: *The lake on the floor of Cirali Obruk is reduced by the declining water table; many artificial cave houses are visible, cut into the shadowed part of the far wall.*

Figure 9: *Yilanli Obruk, now degraded to an almost conical profile.*

The old obruks

The plateau takes its name from its one distinguishing feature – the scatter of very large sinkholes, known locally as obruks (Figs 4 and 5). Doğan and Yilmaz (2011) list nine of the larger obruks that each have diameters of 300–700m and reach depths of 50–200m. However, these are all old features with perimeter slopes that have degraded to leave only small sections of vertical walls; floor diameters are typically only 100–300m. The floors are mainly formed of limestone debris and slumped material from any caprock, with some alluvial sediment and undoubtedly wind-blown loessic silts in the older ones.

Three of the old obruks have lakes on their floors. Kizoren Obruk (also known as Hani Obruk) contains an elliptical lake that is about 220x170m across and at least 120m deep (Fig.6). The lake surface lies below 20m of vertical walls cut into the limestone, above which slopes in the mixed sequence above the Insuyu Limestone rise more than 30m and flare out to a diameter of more than 300m. A pump station and a large factory lie abandoned on its rim. Almost in the centre of the plateau, Meyil Obruk is perhaps the most spectacular of the sinkholes, with an almost circular lake 300m in diameter, though its perimeter walls are nowhere vertical except for a few short and low crags in stronger beds of the upper sequence (Fig.7). The nearby Cirali Obruk reaches deeper into the Insuyu Limestone with terraced cliffs around most of its perimeter; its circular lake was more than 100m in diameter, but the falling water level has halved its size beside a ramp of alluvial sediment (Fig.8). Both these lakes lie nearly 100m below their perimeter plateau, but their waters are less than 20m deep.

The old obruks without lakes are now inactive and degraded to gentler profiles. The larger and deeper, and perhaps younger, have conical profiles with a limited extent of flat floor (Fig.9). Large obruks within the main group near the centre of the plateau (Fig.5) are each around 500m across and around 60m deep. Karain Obruk (Fig.10) has clearly evolved by the coelescing of three smaller adjacent ancestral sinkholes. A similar history is evident at the largest of the old sinkholes, Potur Obruk (Fig11), which is nearly 800m long and has degraded to produce gentle marginal slopes around a wide, flat floor.

In contrast to the deeper obruks, with and without lakes, there are some broader and shallower depressions with well-defined rims and wide floors that are nearly flat. An old obruk close to Seyithaci is more than 70m across but only a few metres deep (Fig.12). Kangalli Obruk is wider and deeper but is similar in profile. By analogy with some of the new obruks (see below), it would appear that the central blocks of ground collapsed only by a few metres during their initial events, and these are not merely deeper features that have filled with debris and sediment.

Figure 10: *The wide open space of the Obruk Plateau, with the Karain Obruk near the crest of a low ridge.*

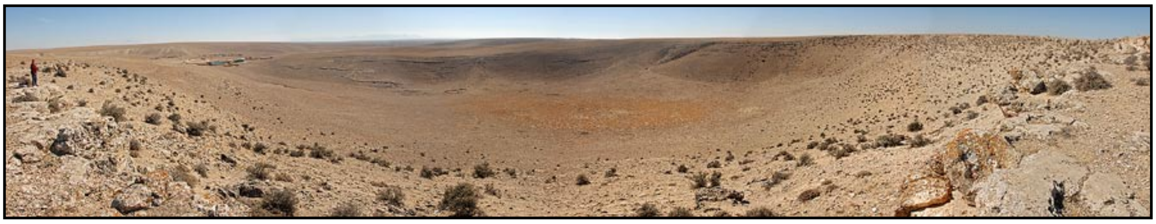

***Figure 11:** The wide bowl of Potur Obruk, the largest of the old obruks in the central part of the plateau.*

***Figure 12:** A shallow old obruk just outside Seyithaci village (Site A on Figure 15).*

***Figure 13:** Akviran Obruk, 78m deep with overhangs in its limestone walls.*

***Figure 14:** Kolca Obruk, formed entirely in the cover of clastic sediments.*

***Note** the person for scale on the far rim.*

The new obruks

Starting in 1977, a rash of new ground failures has produced at least 21 obruks of various dimensions, and this ongoing series of collapse events shows no sign of ceasing. The first of the new crop was Akviran Obruk (Fig.13). Nearly 20m wide, its vertical and overhanging walls drop 78m to a lake. Except for the metre or so of soil cover, its walls have remained very stable within sound limestone, and is still the deepest of the new sinkholes. Two more new obruks formed in 1983, and two years later a hole 10cm across developed within a footpath near Yirce. Canik and Çörekçioğlu (1985) described it in delightful and perceptive words: *"Curious people without the knowledge of outcoming danger have enlarged the hole up to 40–50cm diameter and deepened it to 40cm. Here, a new obruk is to be formed at any moment."* In 2011, Doğan and Yilmaz simply documented the Yirce Obruk as 45m wide and 40m deep, and it is clearly visible on satellite imagery.

Next to form was Kolca Obruk, in 1995, just 120m east of the road across the plateau. Slightly more than 50m across and 26m deep, the exposed sinkhole is entirely within the poorly consolidated clastic sediments that overlie the limestones. Though its perimeter is marked by concentric fractures, its walls remain close to vertical and its degradation is extremely slow in the dry environment (Fig.14).

From 2007 onwards, a suite of seven obruks has developed around the village of Seyithaci on the eastern fringe of the plateau (Fig.15). Five out of the seven are of a different morphology, with diameters much greater than their depths (Fig.16). It would appear that these have formed by a plug of weak caprock dropping almost intact and then resting on a pile of debris that has bulked to nearly fill the underlying collapse zone. The largest and latest of the seven is more than 40m across and almost perfectly circular (Fig.17). Its core dropped by about a metre in an instantaneous event, and subsequently has not moved. One house was destroyed where cut by the perimeter failure, but the ground

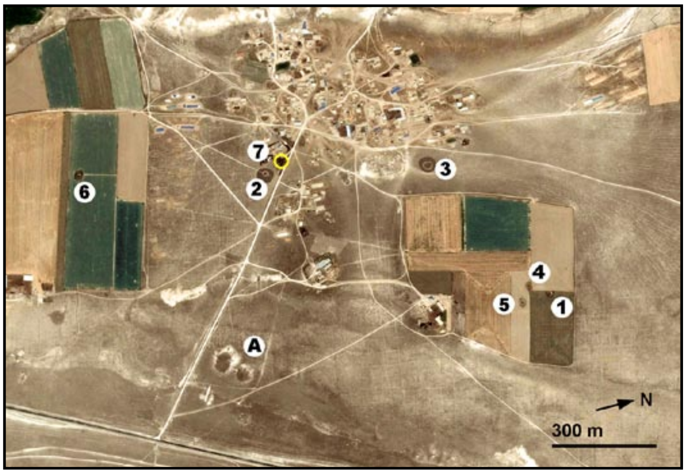

Figure 15: *Satellite image of the village of Seyithaci and its new obruks. The seven numbered sinkholes all formed between 2007 and 2014; their dark outer parts are vegetation inside fenced areas that enclose the smaller collapse features. Number 7 is shown by a yellow ring as it post-dates the satellite image. The two obruks at A are old features. (Base image from GoogleEarth.)*

Figure 16: *Seyithaci Obruk #5, formed in the irrigated fields east of the village.*

inside the perimeter is remarkably undisturbed. The two other obruks near the village are each around 5m wide and deep, and are normal dropout sinkholes developed in cohesive soils. None of the Seyithaci obruks exposes anything other than Quaternary alluvial sediments.

The obruks of Inoba and Akkuyu #3 both developed in the winter of 2008/9 and were each about 25m wide and 35m deep with vertical walls down to lakes at the water table. They are both caprock sinkholes in that their exposed walls are in the Quaternary bedded, clastic sediments overlying the Insuyu Limestone. With a relatively strong bed of siltstone forming its lip, Inoba Obruk now has overhanging walls over aprons of fallen debris that have almost completely filled the lake (Fig.18). It lies less than 150m from the nearest houses in the village of Inoba, and appeared overnight in what had been almost level pasture. For the two previous days, residents of the village had heard strange noises from underground, some saying that they sounded like a large mass falling into water (Doğan and Yilmaz, 2011). This matches reports of underground noises from various sites across the plateau, indicating that collapse is widespread and additional obruks might well develop (Canik and Çörekçioğlu, 1985).

The collapse processes

The obruks are collapse phenomena. Many of the large obruks, both old and new, have broken through sequences of poorly lithified, clastic materials, so are clearly caprock sinkholes. Others are formed in the Neogene limestone, so are collapse sinkholes, unless they origins lie in the underlying, stronger, Mesozoic limestones, in which case they too could be described as caprock sinkholes.

It is clear from the large sizes of some of the sinkholes within the limestone, and from the reported sound effects of underground collapses, that most of the obruks are the consequence of rock failure into large caverns. However, no large caverns have been seen and no collapse has exposed a cave passage, raising the question as to the depth at which caves have developed. At the new collapse obruks, ground has dropped by less than 8m at eleven sites, by 23–40m at four of them, and by more than 69m at two sites. These figures could relate to depths of caves. However, the smaller collapse depths could be due to the failed plugs resting on piles of bulked, fallen debris that partially fill tall caverns (Fig.19); the debris accumulates as the voids migrate upwards by progressive roof stoping. In contrast, the deep obruks such as Akviran and Inoba formed over tall caverns, which were either of considerable size or had an outlet for the fallen rock into a major cave passage. Substantial underground drainage from the limestone Taurus Mountains northwards to Salt Lake passes beneath the Obruk Plateau, and it is not unreasonable to conceive of the existence of major cave passages at depth beneath the plateau. Whether these are in the Mesozoic limestones or the overlying Neogene limestones remains open to speculation.

Figure 18: *Inoba Obruk with vertical walls in the clastic sediments overlying the limestone.*

Figure 19: *Seyithaci Obruk #3, with its intact, 20m-wide, central plug that dropped about 2m.*

The small number of new obruks that are just a few metres wide and deep can be described as subsidence sinkholes within the soil profile, and no similar older features can now be recognized (Fig. 20). Kolca Obruk is clearly a very large subsidence sinkhole formed by suffosional loss of the clastic sediment in which it has formed. The Yirce Obruk was described as having a small initial opening, suggesting that it too developed largely by suffosion and less by collapse.

Events inducing the new obruks

The timing of the series of new obruks correlates roughly with an increase of groundwater pumping for irrigated agriculture across the Obruk Plateau and the Konya Plain (Doğan and Yilmaz, 2011). Multiple well records show that the regional water table has declined by about 24m since 1980. Furthermore, most of the new obruks have occurred in the irrigated farmland. The implication is that the new collapses were induced by either collapse or suffosion or both.

Thin-bedded limestone forming the roof spans of caves may be induced to collapse by the loss of buoyant support when the cave is drained. If such a loss of buoyancy support has been significant, it would indicate the presence of caves within the zone of water table decline, which is nearly 100m below much of the plateau surface and entirely within the Neogene Insuyu Limestone.

Figure 17: *Seyithaci Obruk #7, just a metre deep but destroying the approach road to the village and a single house that unfortunately straddled the zone of the perimeter break.*

Figure 20: *Seyithaci Obruk #6, a subsidence sinkhole about 6m deep.*

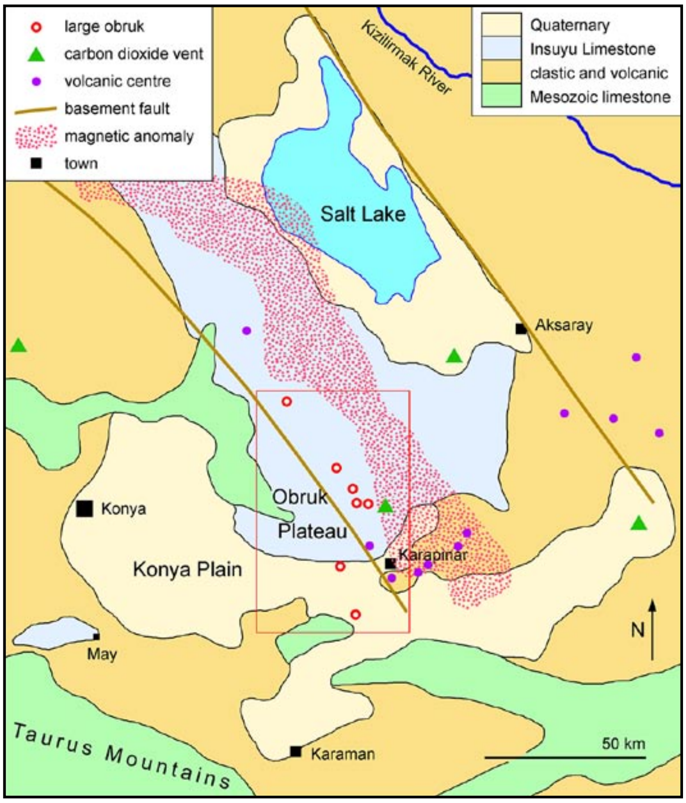

Figure 21: *The Konya Basin, with the Obruk Plateau lying midway between the Taurus Mountains and Salt Lake, with generalized outcrops, and some features of the basement geology from Bayari et al. (2009). The rectangular frame marks the area shown in Figure 4, which includes the locations of more obruks.*

Figure 22: *House destroyed on the perimeter of Seyithaci Obruk #7 in August 2014.*

It is widely known that new subsidence sinkholes are commonly induced by increased inputs of surface water, which then accelerates suffosional loss of soil cover into fissures in the underlying limestone. New irrigation can be a significant factor, unless it is so finely tuned that all the introduced water stays in the soil until it is taken up by plant growth. Additional surface water was a factor where many new subsidence sinkholes opened in the alluvial cover when the May Reservoir was first impounded close to the southwestern corner of the Konya Basin (Doğan and Çiçek, 2002). Suffosional losses of ground have clearly been significant at some of the plateau obruks within the clastic cover sediments, but could also have been contributory to erosion of weaker elements within the poorly lithified Quaternary sequence that subsequently failed by rock collapse on a larger scale at sites including the Inoba Obruk.

Deep-seated genesis of the obruks

The sheer sizes of the obruks, both old and new, appear to be incompatible with processes restricted to the semi-arid region's minimal rainfall entering the thinly bedded, weak and impure limestone sequences at outcrop across the Obruk Plateau. It would seem reasonable that the obruks relate to deeper sources where major flows of groundwater from the Taurus Mountains pass beneath the plateau, whether in the Neogene or Mesozoic limestones or both. Obruk distribution relates little to the surface topography, and the main group of large old obruks lies partly along a ridge, with their linear pattern suggesting some guidance within a fault zone. The cluster of new obruks at Seyithaci lies within the influence zone of a fault that locally separates the Obruk Plateau from the Karapinar arm of the Konya Plain.

Geochemistry of the waters beneath the Obruk Plateau confirms the influence of deep-seated processes, and Bayarai *et al.* (2009) present a strong case for obruk development by hypogenic processes related to rising flows of highly corrosive water beneath the plateau (Fig.21). The volcanic origins of this water are indicated by the isotopic profiles of contained carbon and helium, and by the high levels of fluorine and lithium. Furthermore, volcanigenic carbon dioxide emerges from vents around Karapinar and has been encountered in oil-exploration boreholes. As an ultimate source of the gas, a magmatic body beneath the plateau is indicated by a magnetic anomaly parallel to a northwest–southeast basement fault that underlies the main elongate cluster of obruks (and parallels the eastern margin of the Salt Lake). Volcanism was active around Karapinar until about a million years ago, and was even more extensive in Cappadocia nearby to the east. Perhaps the most convincing evidence for hypogenic activity is in borehole and well data that reveal the content of carbon dioxide in groundwater beneath the Obruk Plateau increasing downstream, towards the north, even while its carbonate load is also increasing.

It is clear that hypogenic carbon dioxide is driving karst processes that are active deep beneath the Obruk Plateau. And it is perhaps typical of karst that the sinkhole development, old and new, has been influenced by multiple factors. At opposite ends of the scale, deep-seated magmatic carbon dioxide and agricultural groundwater abstraction have both contributed to formation of the obruks, whereby the former generated the voids and the latter destabilized their roofs (Fig.22).

Access to the obruks

Many of the obruks are readily accessible to anyone with their own car. The Kizoren and Meyil obruks with their lakes are almost on the tourist trail along with the Meke volcanic crater lake. Most of the large old obruks are close to the good gravel road that crosses the plateau from Kizoren to Karapinar via Akorenkisla and Esentepe. Be aware that some shepherds keep large, ferocious dogs, trained to take on any brown bear (or alien geomorphologist) who might be after their sheep. Of the new collapses, those at Seyithaci are all around the village, which is just off the main road, and Inoba Obruk is easily found just behind the eponymous village, preferably after checking the location on GoogleEarth. The location of Akviran Obruk is well-known to those living in its nearby village.

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