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Geological Model of Korosi Geothermal Prospect, Kenya

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ABSRACT

Korosi geothermal prospect is situated within a shield volcano located in Baringo County within the Kenyan Rift Valley closely edged by Baringo geothermal prospect to the south and Paka volcano to the north. Korosi prospect is positioned in the inner trough of the rift and is marked by quaternary volcanism in the centre and bound by thick sedimentation to the east and west. A fault zone separates Korosi with a smaller volcano- Chepchuk to the northeast. GDC field surveys reveal that a geothermal system with reservoir temperatures of over 250℃ exists. The volcano is uniquely characterized by geological features each of which has been instrumental in the geological buildup of the area. These features in probable chronological order include a tuff ring, shield volcano, normal faults, pyroclastic cones, a crater, volcanic domes and a lava tube. These features are each associated to the major lithological units in Korosi which include pumice, lower Korosi trachytes, basalts and mugearites, pyroclastics, upper trachytes and the young Adomeyon basalts respectively. The Kolobochon tuff ring is unaltered and thinly bedded, and is generally made up of pumice material or material of pyroclastic density. It was formed around a volcanic vent located in a lake or an area of abundant groundwater. Pyroclastic deposits are exposed on the western lower flat plains of the Korosi volcano and are presumed to be the oldest rock unit associated with the volcano. The lower trachytes are perceived to be the Korosi shield forming rocks. Geochemical studies have proven that the main edifice known as Kotang is the upflow zone for the Korosi system. The lower trachytes are intensely faulted and would form good reservoir rocks for the geothermal system. The NNE-trending faults, which superimpose horst-graben topography form good channels for the geothermal fluids and enhance permeability evidenced by the occurrence of manifestations along these fractures. This main phase of faulting was also accompanied by the voluminous eruption of fluid basalt and basaltic trachyandesite lavas which exhibit strong structural orientation. Pyroclastic cones associated with this phase of faulting are also present. The Kinyat Crater is a feature of importance as it signifies an underlying large volcanic vent. This feature is associated with the formation of the upper trachyte rocks as are the gently sloping mounts of trachytic lava that form domes within the prospect. The lava tubes encountered in Korosi are formed by the youngest rocks, the Adomeyon basalts. Although these basalts have not been dated, they appear very young and give the impression that the system is still hot.

1.0 INTRODUCTION

Korosi geothermal prospect is located in the northern sector of the actively faulting Kenya Rift Valley, approximately 300km from the Nairobi capital at approximately 0º45'N and 36º05'E. The Kenya Rift valley hosts immense geothermal resources that are spread out in over ten prospects aligned north to south, two of which are currently been drilled and developed. The prospect which is soon to be drilled is positioned within a shield volcano located in Baringo County closely bound by the Paka and Lake Baringo prospects in the north and south respectively. It occupies an estimated area of about 286 km2 and lies between Eastings 166000 – 193000 and Northings 78000 – 98000. Korosi unlike many Kenyan volcanoes is not characterized by a caldera structure but is marked by young volcanism, faulting and sedimentation that are characteristic of the rift.

GDC's field surveys comprising geological, geochemical, and geophysical surveys as well as heat loss measurements, reveal a mature geothermal system with reservoir temperatures of over 250℃. Hydrothermal activity manifests in form of active fumaroles, steaming and altered grounds complemented by young lava flows which clearly indicate that a heat source subsists. Moreover their presence too implies that fluids have channels through which to circulate, structurally the area is very suitable. Recharge for Korosi system is mainly via lateral flow from the rift flanks due to hydraulic gradient and axially from Lake Baringo (ref) .Geophysical studies, and in particular electrical methods divulge a well-defined cap rock which means that the system is sealed and ensures that fluids do not escape rapidly from the system. The implications therefore are that Korosi volcano is economically viable and sustainable. Following an intensive research with the British geological survey, Dunkley et al (1993) gave the prospect a ranking lower than Silali, Emuruangogolak and Paka based on geology, hydrogeology and fluid chemistry. This finding is however debatable considering that Korosi is in the plateau stage of a volcano meaning that it is free from volcanic hazards and in particular acidic fluids, the resource according to GDC's field surveys is quite promising.

Volcanic activity in Korosi is reasonably well studied and some events are perceived to be contemporaneous with activity in the neighbouring prospects of Baringo and Paka. Incidentally the older basaltic activity is associated with Baringo (clement et al) while the youngest basaltic activity though undated is presumed to be associated with Paka. The published ages for the Pleistocene volcanic formations in Korosi range between 0.38Ka for the oldest and ≤0 .104 Ka for the youngest based on the Ar/Ar method and fields relations by Dunkley et al 1993. However Clement et al (2003) published an age of 92±5 Ka for Korosi' s youngest trachytes which show a slight discrepancy with the age published by Dunkley et al.

Korosi volcano is associated with various geological features, evidently distinctive to the volcano and that are directly related to the geological buildup of the area. These features in probable chronological order include a tuff ring, shield volcano, step faults, pyroclastic cones, a crater, volcanic domes, and a lava tube. The geology of Korosi is dominated by the intermediate trachyte lavas which cover a large portion of the prospect; they are the shield forming rocks. Basalts and mugearites dominate the south and north areas while pumice and tuff deposits are only mapped west of Korosi. Fluvial sediments are quite extensive in the topographic lows around the volcano.

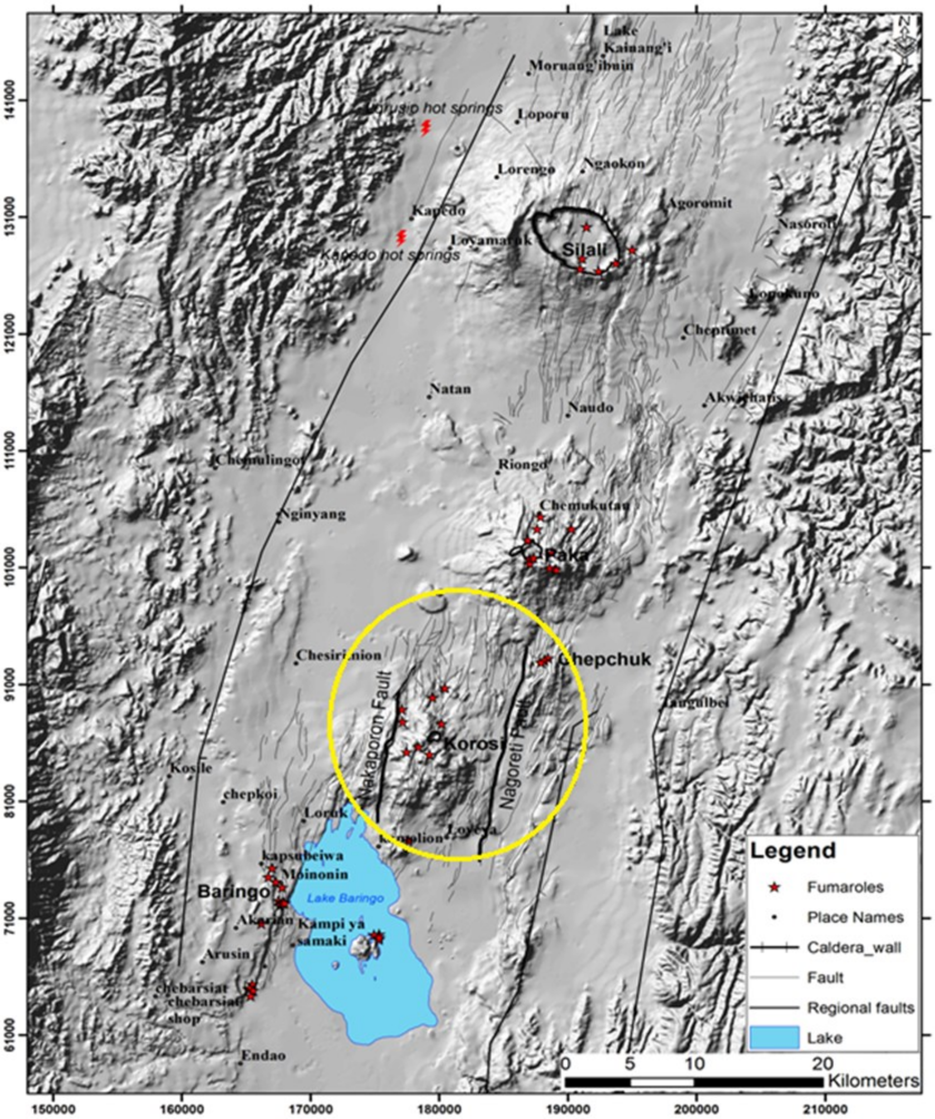

Figure 1: Location map of Korosi volcano

2.0 KOROSI GEOLOGICAL FEATURES

2.1 Tuff ring and associated pumice

A tuff ring is a formation with a low profile apron of tephra surrounding a wide crater that is generally lower than the surrounding topography resulting from relatively wet eruptions (Young 1996). The eruptives of the Kolobochon tuff ring show that rising eruptive material encountered significant amounts of groundwater that initiated eruption phases. Once a critical eruptive: water ratio was exceeded, the eruptions became dry and sub-plinian. For the Kolobochon tuff ring to form, the ground water levels must have been significantly abundant and shallow. It is also probable that the lake Baringo shoreline must have been considerably close as studies by Onyando (2002) reveal that in 1976 the area of the lake was 219 km², in 1986 it was 136 km², in 1995 the areas was 114 km² while in 2001 it was 108 km². This means that the areal extent of the lake was much larger at the time of the eruption which Ar/Ar dates by Dunkley et al (1993) yield an age of 380±7ka. The pumice deposits at Loruk contain paleo river channels identified by arc shaped formations containing rounded clasts that exhibit well sorted fluvial deposits.

The Kolobochon is a large circular formation composed of bedded pumice material that exhibit high alteration particularly on the northern zone where part of the wall is cut off. The deposit exhibits a brown colour where altered and a grey colour where fresh. The pumice are also not well compacted and crumble when struck with a hammer. Evidence of fracturing and faulting is apparent in the eruptives where slight displacement is obvious. The Kolobochon tuff ring is perceived to be the monogenic source of the pumice material found to the west and south of Korosi prospect as the deposits are fairly similar. The pumice deposits are the oldest lithological units exposed in Korosi, based on the law of superposition and the dating of alkali feldspar crystals done by Dunkley et al (1993).

It is anticipated that the pumice deposits will be encountered during drilling of geothermal wells and are presumed to be part of the Korosi capping system.

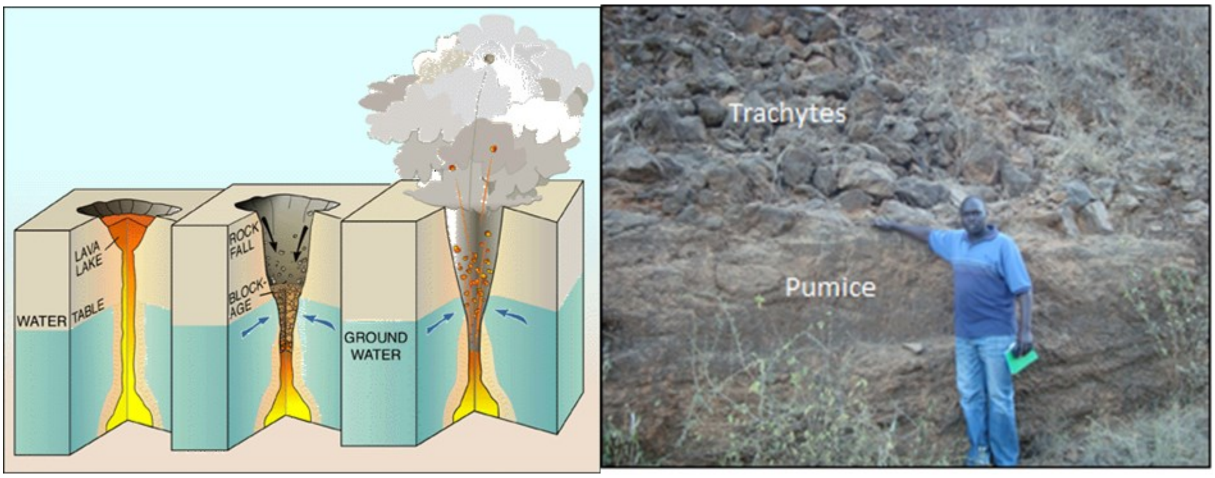

Figure 2. (a) Formation of tuff rings, (b) the Korosi lower trachytes

2.2 Shield volcano and associated lower trachytes

Shield volcanoes are large low angle volcanoes characterized by flow of relatively fluid lava. The volcanoes usually have broad sloping sides and are surrounded by gently sloping hills. Seven of the Kenya rift volcanoes have low-angle, shield like forms, and comprise lavas, pumice tuffs and ash-flow tuffs almost wholly of trachytic composition (Webb and Weaver 1975). According to the various literatures, these volcanoes may be characterized as mature shield volcanoes if they measure 5 to 6 km in diameter and surpass 460 to 610 m in height. Korosi measures approximately 12km in diameter, rises 450-550 m above the rift floor and can thus be classified as a mature shield volcano.

The lower trachytes which conformably overlie the pumice are perceived to be the oldest shield forming rocks. The lavas were erupted from vents along fractures, the main vent being Kotang as it forms the summit of the volcanic complex. The rocks also have poorly preserved flow features that show Kotang to be a polygenic source point of the old trachytes. The lavas are quite extensive covering over 20 km from north to south. However, the lavas do not appear to flow very far to the east and west possibly because they are obscured by the thick pile of sediments along the Nakaporon and Nagoreti faults.

Dunkley et al (1993) used Ar/Ar dating method and came up with an approximate age of 307±2ka for these lower trachytes. The rocks are generally grey and greenish grey when fresh but, depending on the degree of alteration exhibit reddish brown and green discolouration. Alteration of this formation to low temperature clays such as smectites is confirmed by resistivity surveys which designate low resistivity on the surface. The lavas also exhibit intense fracturing and faulting, with most of these features being open. The lavas being the oldest have been exposed to most of the recent tectonic events within the region. Heat loss surveys conducted by GDC 2011 reveal an interesting pattern; the areas with the highest heat loss values after probing 1 m deep are associated with the lower trachytes. These values are confirmed by the CO_2 concentration values that reveal a similar pattern as CO_2 emissions are also related to permeable zones in volcanic geothermal fields.

These high heat loss values are due to the fact that heat is allowed to circulate through the open faults and fractures in the lower trachytes of Korosi. The hottest fumaroles referred to as KF1 and KF3 are located near Kotang and along the Nakaporon fault where fractured lower trachytes dominate. The gas contents of fluids present in areas of high permeability and close to a hot geothermal fluid up-flow are expected to be high especially with regards to the reactive gases Based on geochemistry analysis, gas solubility mentioned, it is observed that in a boiling system the least water-soluble gases are released faster but the more soluble ones are released slowly. From this argument, close to the upflow of the hot geothermal fluids the ratio of a less soluble to that of a more soluble gas should be high and should decrease in the direction away from the upflow. This therefore suggests that KF-1 and KF-3 are located close to a hot geothermal source in Korosi possibly an upflow zone.

Table 1: Gas ratios in Korosi fumaroles

Fumarole	CO_2/H_2S	CO_2/N_2
KF-1	45462	0.39
KF-2	22704	1.37
KF-3	36789	0.09
KF-4	24062	7.83

2.3 Faults/Fissures and associated basalts and mugearites

The tectonic episodes in the Korosi area are related to strong stresses at depth that have been active for long periods of time. Events located within the Rift show a marked north-south linearity extending from Lakes Bogoria and Baringo in the south, into the Suguta

Valley to the north (Pointing et al 1985). Faults and fissures around the Korosi volcano are so obvious that they can be discerned from satellite imagery. The orientation trend is strongly pronounced in a NNE-SSW direction with the major bounding faults being Nakaporon to the west and Nagoreti to the east.

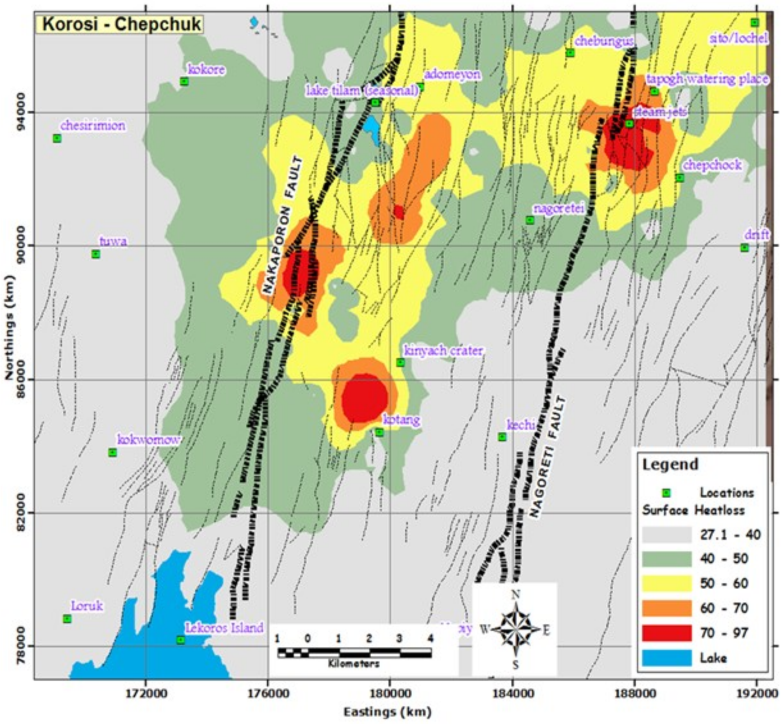

Figure 4: Heat loss measurements of Korosi

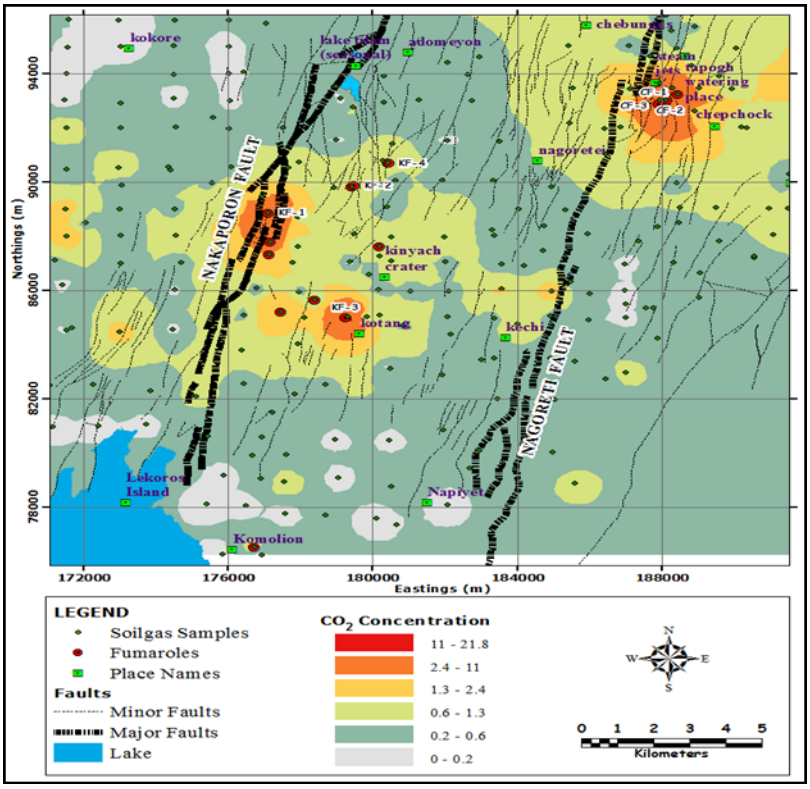

Figure 5: CO2 concentrations in the soil gas

Typically fissure eruptions spring up around the base of a central volcano as is the case in Korosi. The fissure lavas classically cover the northern and southern sectors of the volcano and spread for kilometers in the low lying areas. The basalts and mugearites are several meters wide but can range in length up to many kilometers in length; they are easy to spot when on the ground or from a bird's eye view because they form elongated mounts. The lavas are clearly fissure eruptions as they are structurally aligned. According to Carney (1972), their alignment implies that they were formed during a major faulting episode. The basalts are overlain by the upper trachytes and in turn overlie the lower trachytes. The lavas are porphyritic and contain phenocrysts of olivine, pyroxenes, and plagioclase. Dunkley et al (1993) dated a lava sample by from a fault scarp near Komolion which gave an Ar/Ar date of 121±37Ka. The rocks are dark grey to greyish brown in colour are slightly vesicular and exhibit fracturing.

Permeability in many reservoirs is believed to relate largely to intrusive boundaries and major faults. A good example is the Hengill volcano where NE-SW basaltic dykes of 2000 and 5000 year old fissure eruptions, are believed to provide the main geothermal flow channels of the system (Franzson et al 2005). Thus if fissure eruptions, are believed to provide the main geothermal flow channels of a system then Korosi is expected to be high temperature reservoir with good flow channels.

2.4 Pyroclastic/scoria cones and associated pyroclastics

Most mature shield volcanoes have multiple cones on their flanks. This is because in the final stages of shield volcanoes, pyroclastic ejections are more common. The Korosi pyroclastic cones, form as parasitic features on the flanks of Korosi where they overlie the basaltic formation and also on the Korosi summit where they overlie the upper trachytes. The cones are structurally aligned an indication that their vents are as a result of post- shield building tectonics. The pyroclastic cones/scoria cones are aligned NNE- SSW an indication that they are structurally controlled. They range from a few tens of meters to a few hundred meters in height. These geological formations were most probably formed during single eruptions due to their uniform degree of alteration. The cones are layered and contain white mineral deposition due to migration of meteoric water. The chemical composition of the cones appears basaltic and trachytic and the rocks are frothy and disintegrate easily.

2.5 Kinyat Crater and the upper trachytes.

The Kinyat Crater is a feature of importance as it signifies an underlying large volcanic vent. The floor of the crater has portions of altered ground an indication that the vent is a conduit of heat transfer. This is an indicator of an existing heat source within Korosi and hence proves the existence of a geothermal system. Iso-resistivity maps at 3km below sea level reveal a high resistivity anomaly within the vicinity of the Kinyat crater which can be attributed to the proximity of molten material. The poorly consolidated scoria and pumice deposits that surround the crater signify that material was ejected explosively leaving a conically shaped structure with steep slopes. The Kinyat crater is associated with the formation of the upper trachyte rocks. The upper trachytes according to Ar/Ar dating by Dunkley et al (1993) were formed 104±2 Ka BP. The rocks cover much of the central part of Korosi and extend northwards where they overlie the lower trachytes. A major distinction between the lower and upper trachytes is the degree of faulting as the later are less faulted. Thus it is correct to assume that a major faulting episode occurred after deposition of the lower trachytes and before deposition of the upper trachytes i.e. between 307Ka and 104Ka.

Figure 6: Basaltic fissure flow

Figure 7: Korosi Scoria cones

Figure 8: Kinyat crater

Figure 9: Adomeyon basalt

2.6 Lava domes and associated upper trachytes

The Korosi lava domes are gently sloping mounts of trachytic lava associated with the eruption of the upper trachyte lavas. It is not surprising that the relatively steep domes form on the upper trachytes because during the culmination stage of many shield volcanoes the lava becomes less fluid, thus flow for shorter distances forming steep mounts at the summit area. The domes are characterized by extensive altered ground and high surface temperatures and alteration. The lava domes and their associated trachytes cover much of the central part of Korosi and extend northwards where they overlie the lower trachytes.

2.7 Lava tubes and associated young basalts

The Adomeyon basalt is the youngest eruptive flow in the Korosi area and is clearly discernible from satellite images. The lava is undated but is estimated to be only a few thousand years old based on its fresh appearance, unvegetated state and its lack of fracturing. Its existence is an indication of the existing heat source within Korosi. The basalts are characterized by collapsed lava tubes presumed to be formed by volcanic basalt conduits moulded by the hardening of overlaying lava. The adomeyon lava tubes are hallmarks of the Korosi shield volcanism and account for the final stage of shield volcano activity. The basalts are generally aligned in a northerly direction and are black in colour characterized by vesicles some of which are infilled with calcite.

The presence of the young lava flows can be used to infer the existence of a molten magma body at depth. Furthermore, geoscientific studies reveal the presence of molten material at approximately 3km below the surface; this can be interpreted to prove that a heat source is present within the prospect.

3.0 CONCLUSION

The geological features in Korosi are uniquely associated with the existing lithologies each of which was formed at different times. The geological model of Korosi displays a geothermal system that is active and sustainable. The plumbing system in Korosi is fairly complex as it involves bimodal volcanism of trachyte with associations of basalts and mugearites.

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