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RESEARCH ARTICLE

Interpretation of Geothermal Magnetic Depths, Physicochemical Parameters and Heavy Metals Determination of Lamurde Hot-spring in the North-Eastern Benue Trough, Nigeria

Mukaila Abdullahi[1*] **Yunis B. Valdon[2]** **Fartisincha P. Andrew[1]** **Adamu Usman Abba[3]** **Ibrahim Maigari[4]**

1. Department of Science Laboratory Technology, Modibbo Adama University, P.M.B. 2076, Yola, Nigeria
2. Department of Geology, Modibbo Adama University, P.M.B. 2076, Yola, Nigeria
3. Nigerian Geological Survey Agency (NGSA), Abuja Office, 900108, Nigeria
4. Office of the Surveyor General, Adamawa State, Jimeta-Yola, 640001, Nigeria

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ABSTRACT

An integrated interpretation of the magnetic data and the analysis of physicochemical parameters and heavy metals from Lamurde hot spring has been done for the first time. The temperature of the hot spring was measured to be at 44 °C while the normal surface temperature is 25 °C. Three prominent magnetic anomalies were found at bottom depths of 11.379 ± 0.253 km, 13.015 ± 2.120 km and 9.161 ± 1.200 km suggesting that the Lamurde hot-spring is heated at deep mantle (13.015 ± 2.120 km) and issued to the surface through either local or regional fault system or both. The physicochemical analysis gave pH (7.93 ± 0.06), total chlorine (125.0 ± 2.89 µg/L), total dissolved solids TDS (202.0 ± 2 ppm), hardness (64 ± 1.73 µg/L), alkalinity (210 ± 4 µg/L) and nitrate (1.3 ± 0.3 µg/L). In comparison with that of WHO standards, the results indicated that all the physicochemical parameters studied except for alkalinity fall within the permissible limits. Heavy metals were identified and analyzed in the sampled water: lead (0.1501 ± 0.0007 mg/L), chromium (0.0729 ± 0.0007 mg/L), nickel (0.1987 ± 0.1476 mg/L), cadmium (0.0115 ± 0.0003 mg/L), copper (0.0442 ± 0.0008 mg/L), arsenic (0.0456 ± 0.0003 mg/L), iron (0.8016 ± 0.0005 mg/L), cobalt (0.0274 ± 0.0004 mg/L), selenium (undetectable), manganese (5.31 ± 0.0361 mg/L) and zinc (0.1629 ± 0.0004 mg/L). The concentrations of heavy metals observed in the area with the exception of Zn, Cu and Se are all above the standards for drinking water. Their concentrations are in the order of Mn > Fe > Ni > Zn > Pb > Cr > As > Cu > Co > Cd > Se. These results suggest that the Lamurde hot spring is a potential zone for Mn, Fe, Ni, Zn and Pb deposit.

*Corresponding Author:

Mukaila Abdullahi,

Department of Science Laboratory Technology, Modibbo Adama University, P.M.B. 2076, Yola, Nigeria;

Email: mukailaa.agp@mau.edu.ng

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1. Introduction

The study of geothermal energy reserves of hot springs, from different geophysical data and methods, has been the interest of geophysicists to interpret the thermo-tectonics of a region [1-4]. Spatial mapping of thermally potential zones from a geophysical point of view requires prior information that could be in connection with the tectonic orogeny of the region [5]. Hot water from inside the ground as a result of naturally occurring geological or tectonic phenomena of the past is what is known as 'hot spring'. A study of the Lamurde thermal (hot) spring was recently conducted using geophysical data [3,6]. Hot water from springs habitually contains huge volumes of dissolved minerals in it with low pH [7,8].

The geochemistry of hot springs provides a better understanding of the physicochemical constituents of water under study as well as its origin, re-charging circumstances and heavy metals present. In a region under an intense volcanic regime, the physicochemical characteristics of hot spring in such regions are altered.

Lamurde hot spring is a sedimentary-volcanic region, which is expected to have huge concentrations of unlikeable and more toxic elements like arsenic, iron, lead, manganese and so on whose presence is guided by pH value and other chemical conditions [9].

In the present work, analysis and interpretation of geothermal potential from magnetic signature and physicochemical parameters and heavy metals from sampled water of Lamurde hot spring has been done.

2. Geology of the Study Area

The Lamurde hot spring has a measured area of approximately 13.465 km square. The region (Figures 1 and 2) is characterized by undulating surfaces [6]. The area has a maximum sedimentary thickness of 6.5 km [10,11].

The Tertiary-Recent sediment of the study area has been compressionally folded, faulted and uplifted in several places during the mid-Santonian tectonic episode, producing a series of deformational structures including the Lamurde anticline as one of the major deformational structures in the Upper Benue Trough [6]. The major fracture associated with the Lamurde anticline is the Barashika fault which cross-cut the Cretaceous sediment. The Barashika fault provided the post-depositional zones that are favourable for uranium concentration in the area [10,6]. Hence, the area of Lamurde hot spring is associated with heat-generating lithological factors with a measured hot spring temperature of 44 °C while the normal surface temperature is 25 °C.

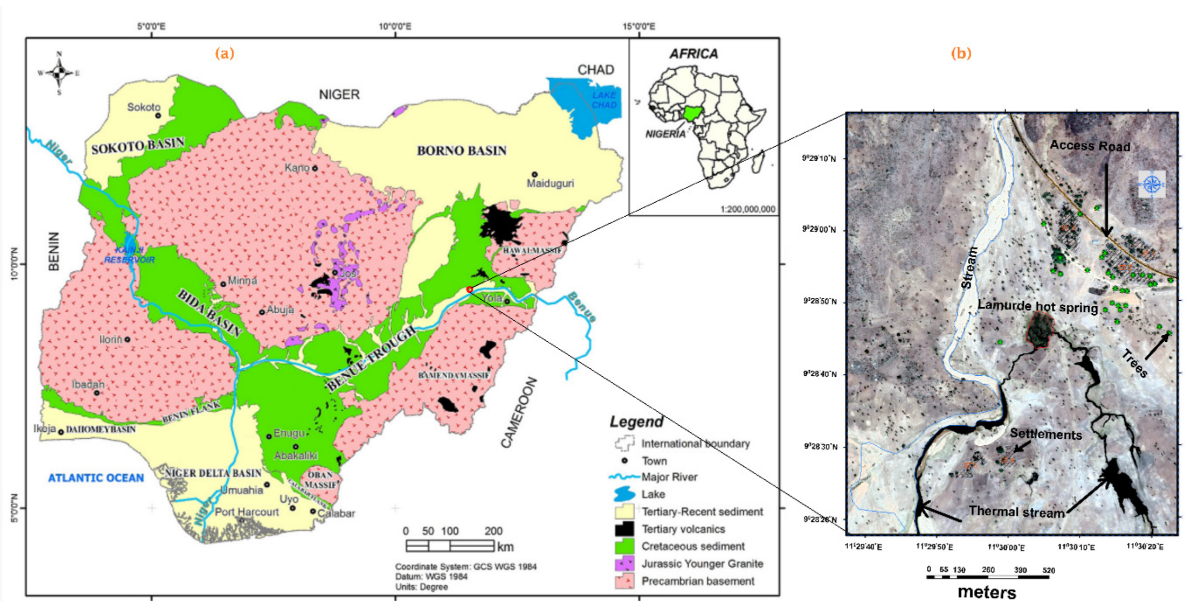

Figure 1. (a) The geological map of Nigeria shows the location of study. (b) The ground Google map, depicting the location of the Lamurde hot spring (Ruwan Zafi) measured approximately 13.465 km square and two channels through which the water from the hot spring run into the main water of the river Benue (i.e., named the thermal streams). These are shown in a distinctive black.

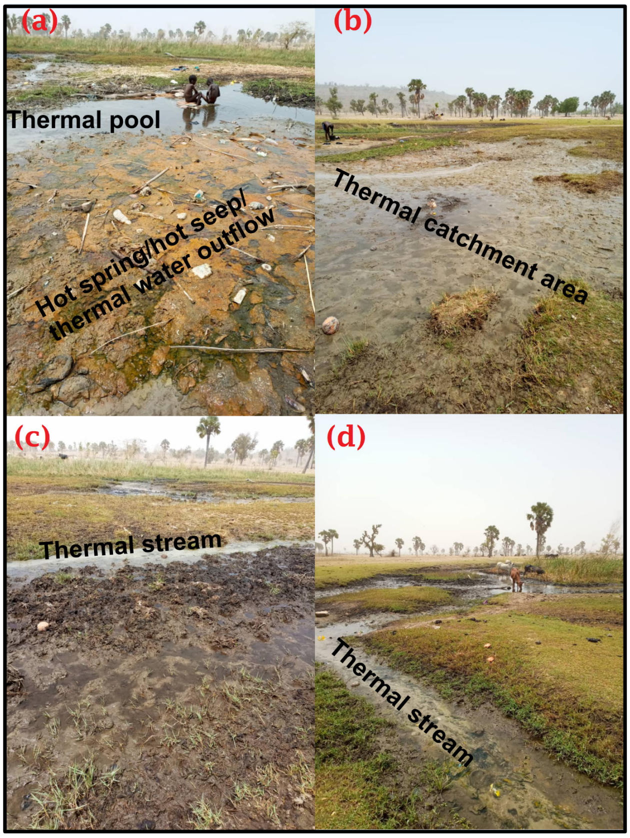

Figure 2. The Physical photographs of the Lamurde hot spring and environs. The hot spring temperature is measured to be 44 °C from the central hot-spring/hot-seep/thermal-water-outflow zone (a) and thermal-catchment area (b) while the normal surface temperature is 25 °C. The thermal-pool (a) is relatively warm around 39 °C where people from the near village called Kwanan Ruwan Zafi sit in to take their baths. Discussions with people from the village revealed that the area of the hot spring/hot-seep/thermal-water-outflow is very dangerous in fact is a no-go zone. The two channels through which the water from the hot spring run into the main water of the river Benue are named the thermal streams (c and d).

3. Data and Methods of Study

The magnetic anomaly of the area of study is shown in Figure 3. On the anomaly map, observed three prominent anomalies. By implication, the zone of low magnetic value could be associated with thick sediment or basin structure and the zones of high magnetic values are in connection with the near surface features or basement. From the prominent high anomaly marked (C2), the signature of the Lamurde hot is delineated and shown by a black star mark. The selected window cells (C1, C2 and C3) are the sizes of anomaly taken for the power spectrum of the calculation of bottom magnetic depths in the area under study.

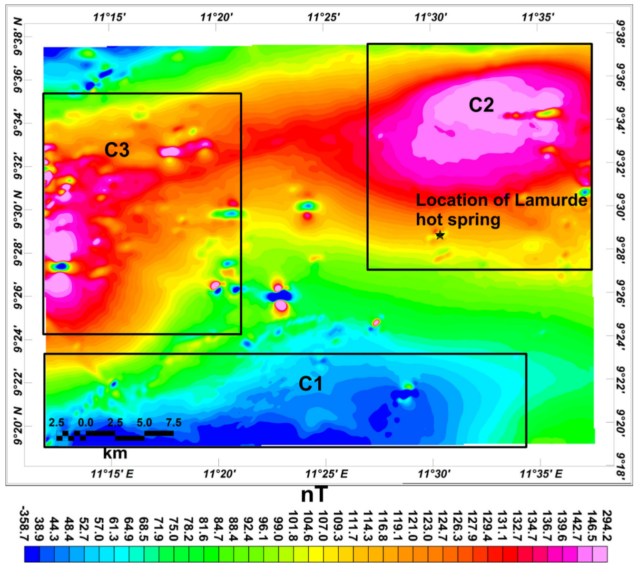

Figure 3. TMI map of the study area delineating the location of Lamurde hot-spring (shown with black star mark). The three prominent anomalies are taken as cells (C1, C2 and C3) for the spectral power spectrum for the calculation of the geothermal parameters.

3.1 Method of Estimation of Bottom (Curie) Depths

Curie depth with the utilization of the centroid method has been done in detail, application of the aeromagnetic data of the SW region of the Benue trough [3]. The approach is the modification of Spector and Grant [12] on the basis of a power law, to describe geologically, the heterogeneity of magnetization within a region [13-18,3].

Simultaneous calculations of depth and 'a parameter' of scaling exponent from magnetic anomaly for the interpretation of the geology of a region are usually non-consistence [19-21]. The scaling exponent for a region of known geology assumed a fixed value [21,22]. Hence, in this study, the unity value of the scaling exponent for the regions' geology is used for the depth computations.

3.2 Chemical Analysis of Water Sample from the Lamurde Hot-spring

All the chemicals and reagents used in this study were of analytical grade. Ethylene diamine tetra acetic acid (EDTA), sulphuric acids (H_2SO_4), methyl red indicator, ammonium buffer, ethanol and phenolphthalein indicator were purchased from commercial sources. Deionized water was used for the preparation of the sample and the standard solutions of the heavy metal ions.

The water sample was collected in a washed and cleaned polyethene bottle. During sampling, the bottle was rinsed thrice with the water to be sampled. The collected sample was transported to the laboratory and kept in a refrigerator for further analysis. The water sample was digested and prepared by methods [23].

Alkalinity and hardness were determined by EDTA titration, while nitrate, chlorine and heavy metals were determined by instrumental methods using a HACH Benchtop DR3900 spectrophotometer DR3900 and BUCK scientific 205 Atomic Absorption Spectrophotometer.

4. Results and Discussion

4.1 Geothermal Properties from High-resolution Aeromagnetic Data

Figure 4 shows the calculated depths from window cell C1 whereas. Table 1 presents the result of depths estimate of the top (Z_t) depths (km) and centroid (Z_0) depths (km) and bottom (Curie) depths (Z_b) in the area under study for the three window cells (C1, C2 and C3). These depths can be considered only provisional because the area of study is small for good resolution of depth interpretations [3]. The top depths have been calculated between 0.507 ± 0.0416 km and 0.966 ± 0.0576 km. These depths could be interpreted as the thickness of the tertiary-recent sediment within the region of study. The centroid depths as calculated between 4.46 ± 0.5790 km and 5.80 ± 0.0976 km are found comparable and inconsistent to the magnetic basement [18] calculated from the south-western region (middle and lower Benue trough). The present result of the bottom (Curie) depths between 9.161 ± 1.200 km and 13.015 ± 2.120 km are comparable with those calculated in the combined middle and lower Benue trough [3]. A higher calculated Curie depth of 13.015 ± 2.120 km is found over the location of Lamurde hot-spring which also interpreted a higher magnetic basement of 6.43 ± 1.0400 km. The intermediate Curie depth of 11.379 ± 0.253 km and magnetic basement of 5.80 ± 0.0976 km is calculated over the low magnetic zone in the study area. It could be expected that high magnetic basement as well as Curie depth to have been calculated over the low magnetic value [18,3]. In this case, it could be that basement is high but possibly intruded by low susceptibility material. The depth differences (approximately 2 km) from the three anomalies could indicate or suggest that the geothermal manifestation of the Lamurde hot spring is structurally controlled by local and regional deep fault systems.

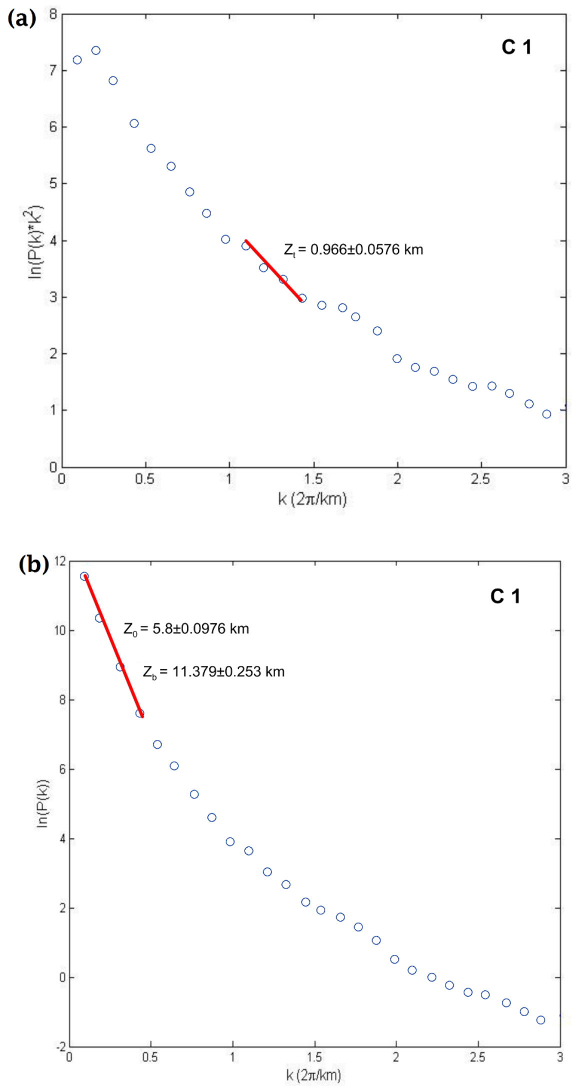

Figure 4. Plots of power spectrums for the computation (a) of the top (Z_t) and (b) centroid (Z_0) and bottom (Z_b) depths with standard errors with the red lines showing the selected best fit in the C1 window cell.

Table 1. Estimated geothermal parameters with standard error from the high-resolution aeromagnetic data of the study area.

Cell number	Depth to top (Z_t) in km	Depth to centroid (Z_0) in km	Depth to bottom (Z_b) in km
C1	0.966 ± 0.0576	5.80 ± 0.0976	11.379 ± 0.253
C2	0.600 ± 0.0311	6.43 ± 1.0400	13.015 ± 2.120
C3	0.507 ± 0.0416	4.46 ± 0.5790	9.161 ± 1.200

4.2 Physicochemical Parameters of Water Sample

The important physicochemical parameters namely pH, total chlorine, total dissolved solids, total hardness and nitrate in comparison with that of WHO are presented in Table 2. The result indicates that all the physicochemical parameters studied except for alkalinity fall within the WHO permissible limits. The pH of the water was found to be 7.93 ± 0.06, which is within the WHO permissible limit. This indicates that according to the pH, the water is fit for drinking, recreation, agricultural and aquatic uses [24].

The total dissolved solids (TDS) consist of both ionized and unionized matter in water. The desirable limit of TDS in drinking is in accordance with WHO ranges (500-1000 ppm). The TDS of the water sample analyzed was found to be 202.0 ± 2 ppm which is within the WHO permissible limit.

The mean value of chloride, hardness and nitrate in the water sample were 125.0 ± 2.89 mg/L, 64 ± 1.73 mg/L and 1.3 ± 0.3 mg/L which is within the WHO values of 250 mg/L, 200 mg/L and 3 mg/L respectively. However, that of alkalinity (210 mg/L) is slightly above the WHO permissible limit (200 mg/L). High alkalinity has some positive effect of buffering acid rain and other acid waste that may have been washing off into the water body, thereby preventing pH changes that may be harmful to aquatic lives [25].

Table 2. Physicochemical parameters of the water sample and WHO permissible limit.

Parameters	Water sample	WHO permissible limit
pH	7.93 ± 0.06	6.5-8.5
Chloride (μg/L)	125.0 ± 2.89	250
Total Dissolved Solids (ppm)	202.0 ± 2	1000
Hardness (mg/L)	64 ± 1.73	200
Alkalinity (mg/L)	210 ± 4	20-200
Nitrate (mg/L)	1.3 ± 0.3	3

4.3 Heavy Metal Analysis

The heavy metals analyzed include lead, chromium, nickel, cadmium, copper, arsenic, iron, cobalt, selenium, manganese and zinc. The concentration of the heavy metals observed is shown in Figure 5 except for Zn, Cu and Se, all the metals analyzed are beyond the WHO permissible limit. The concentration of lead was averagely found to be 0.1501 ± 0.0007 mg/L higher than the 0.01 mg/L WHO permissible limit. The concentration of nickel and iron were found to be 0.1987 ± 0.1476 mg/L and 0.8016 ± 0.0005 mg/L which are above the WHO permissible limit of 0.07 and 0.3 mg/L respectively. Similarly, the concentration of chromium, cadmium and arsenic were found to be 0.0729 ± 0.0007 mg/L, 0.0115 ± 0.0003 mg/L and 0.0456 ± 0.0003 mg/L also above the WHO limit of 0.05 mg/L, 0.003 mg/Land 0.01 mg/L respectively. The concentration of manganese was the highest 5.31 ± 0.0361 mg/L above the 0.5 mg/L WHO permissible limit, while selenium was below the detectable limit. Cobalt was found to be 0.0274 ± 0.0004 mg/L, although, there is no any WHO prescribed guideline value for cobalt. For zinc and copper, the concentration was found to be 0.1629 ± 0.0004 mg/L and 0.0442 ± 0.0008 mg/L which is within the WHO permissible limit of 3 mg/L and 2 mg/L respectively. The concentration follows the order Mn > Fe > Ni > Zn > Pb > Cr > As > Cu > Co > Cd > Se.

These results suggest that the Lamurde hot spring is a potential zone for Mn, Fe, Ni, Zn and Pb deposit. The concentration of Mn is the highest followed by Fe. Water with high concentrations of Fe and Mn is not healthy for human consumption [9]. Manganese (Mn) is not found as a free element in nature but in combination with iron and other minerals. It is a metal with important alloy uses and specifically in stainless steel. Iron and manganese are similar in chemistry and the manner; they are distributed and concentrated in rocks [9]. They originate from the Earth's crust and mantle and are usually described as the products of continental weathering, seafloor hydrothermal activity and sediment diagenesis [8,9]. The fraction of the iron and manganese from the continental weathering of which the volcanic Lamurde hot spring is one is more geologically recycled than that from the oceanic crust and the sediment diagenesis in this regard is the process for further recycling of the metals (Mn and Fe) within the sediment's column [9].

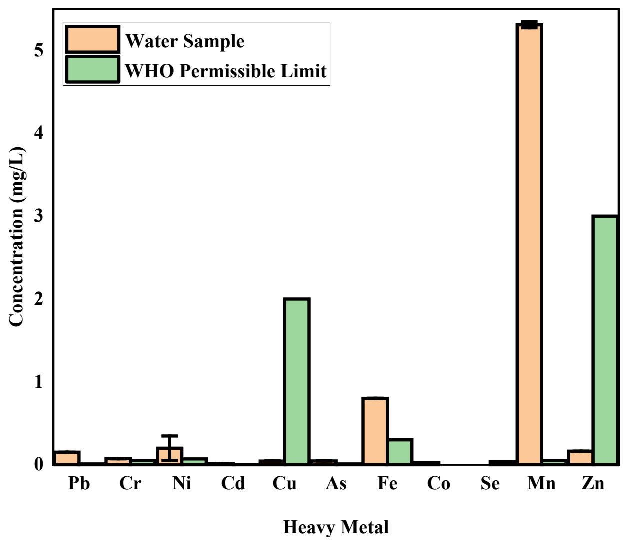

Figure 5. The mean value of the heavy metals compared with WHO Standard permissible limit.

5. Conclusions

The high-resolution aeromagnetic data of this region is analyzed. From the magnetic data, we see a fault signature from the location of the Lamurde hot spring. The large differences of geothermal depths (which is beyond 2 km) calculated over the three magnetic anomalies in the region are also an indication that the water from the Lamurde hot-spring is heated from deep (13.015 ± 2.120

km) Earth's mantle and issued at the surface through a volcanic fault system.

The Lamurde volcanic hot-spring content concentrations of metals in the order: Mn > Fe > Ni > Zn > Pb > Cr > As > Cu > Co > Cd > Se. Determination of the amount of these elements in the hot spring is in order to protect public health. This study showed that the concentration of Fe and Mn are significantly higher than acceptable standards in drinking water.

Author Contributions

Mukaila Abdullahi **(MA)**, Yunis B. Valdon (**YBV**), Fartisincha P. Andrew **(FPA)**, Adamu Usman Abba (**AUA**), Ibrahim Maigari (**IM**).

MA, FPA were responsible for project conceptualization, administration, data collection, analysis, literature work, funding acquisition and writing of the original draft of the article. **MA**, **YBV, AUA** and **IM** were responsible for the geological survey of the study area, data generation, review and final editing. Additionally, **FPA** and **MA** were responsible for the chemical analysis of the water sample from the study area and correspondence respectively.

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Data Availability Statement

The data used in the work is readily available on request from the corresponding author.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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