Analysis of High Resolution Seismic Reflection Data to Identify Different Regional Lithologies of the Zaria Batholith Located in the Basement Complex of North Central Nigeria

Collins C. Chiemeke, A. Onugba, P. Sule

***Abstract*—**High resolution seismic reflection has recently been carried out on Zaria batholith, with the aim of characterizing the granitic Zaria batholiths in terms of its lithology. The geology of the area has revealed that the older granite outcrops in the vicinity of Zaria are exposures of a syntectonics to late-tectonic granite batholiths which intruded a crystalline gneissic basement during the Pan-African Orogeny. During the data acquisition the geophone were placed at interval of 1 m, variable offset of 1 and 10 m was used. The common midpoint (CMP) method with 12 fold coverage was employed for the survey. Analysis of the generated 3D surface of the p wave velocities from different profiles for densities and bulk modulus revealed that the rock material is more consolidated in South East part of the batholith and less consolidated in the North Western part. This was in conformity with earlier identified geology of the area, with the South Eastern part majorly of granitic outcrop, while the North Western part is characterized with the exposure of gneisses and thick overburden cover. The difference in lithology was also confirmed by the difference in seismic sections and Arial satellite photograph. Hence two major lithologies were identified, the granitic and gneisses complex which are characterized by gradational boundaries.

***Keywords*—**Basement Complex, Batholith, High Resolution, Lithologies, Seismic Reflection.

I. Introduction

SEISMIC reflection profiling involves the measurement of the two-way travel time of seismic waves transmitted from surface and reflected back to the surface at the interfaces between contrasting geological layers. Reflection of the transmitted energy will only occur when there is a contrast in the acoustic impedance (product of the seismic velocity and density) between these layers [4]. 2-dimensional (2D) and 3-dimensional (3D) high-resolution seismic reflection survey techniques provides a better understanding of geologic heterogeneities [8]. The shallow seismic reflection technique is relatively straightforward from a conceptual perspective. Ideally, a high frequency, short-duration pulse of acoustic energy is generated at the earth's surface, and measure the arrival times and magnitudes of "echos" that are reflected from subsurface acoustic horizons (i.e., water table, bedrock, lithologic and facies contacts, etc.) and returned to the earth's surface [1]. High resolution seismic survey can provide result which compares well with direct observation and trenching on land [9]. Four processes affect the formation of metamorphic facies, contact metamorphism, in which heat from magma changes the rocks; burial metamorphism, in which heat from the earth's interior causes metamorphism; subduction of rock, in which a tectonic plate sinks under another tectonic plate, causing volcanic arc metamorphism, in which the formation of volcanoes near a plate boundary causes metamorphism [6]. The aim of this research work is to make use of high resolution seismic reflection survey to identify the different lithologies that characterize the Zaria batholith and its environs. The instruments used include: the Terraloc Mark6 digital seismograph, vertical geophone, reels of cables with take-outs and sledge hammer strike on base plates.

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II. Location of Study Area

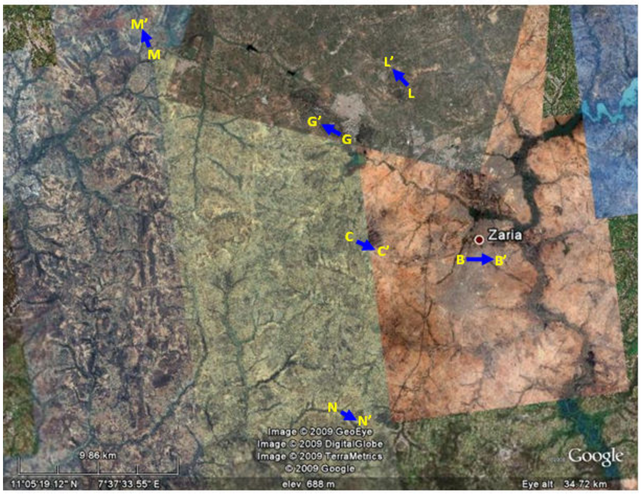

Fig. 1 Location map of the study area showing profile lines in blue with the arrow head pointing in the direction of profile. Adapted from Google earth

The study area is Zaria batholith (Fig. 1), located in the Basement Complex of Northern Nigeria. It is bounded by Latitude 11° 13' 52.37" N, Longitude 7° 41' 49.26" E and Latitude 11° 06' 16.72" N, Longitude 7° 42' 11.56" E, with average elevation of 650 m. The seismic reflection profile lines are shown in blue, the direction of the arrows shows the direction of the profile. The profile includes: profile L-L' located at Bassawa, profile N-N' located at Dumbi, profile C-C' located at Kufena Hill, profile G-G' located at Kubani River, profile M-M' located at Tsibirin Sambo and profile B-B' located at Tuden Wada, all these are names of Towns and Villages located within the Zaria batholith, in the basement complex of central Northern Nigeria. The coordinates of the profiles are shown in Table I. The geological map of the survey area is shown in Fig. 2.

TABLE I
LONGITUDE AND LATITUDE CO-ORDINATES OF THE PROFILES ANALYZED FOR VELOCITY, DENSITIES AND ELASTIC PARAMETER

Location and Profile Line	Longitude (Degrees)	Latitude (Degrees)
Tsibirin Sambo M-M'	7.538000	11.19553
Tuden Wada B-B'	7.718717	11.08167
Kufena Hill C-C'	7.652367	11.08430
Bassawa L-L'	7.675083	11.17390
Dumbi N-N'	7.646033	10.97565
Kubani G-G'	7.634833	11.14787

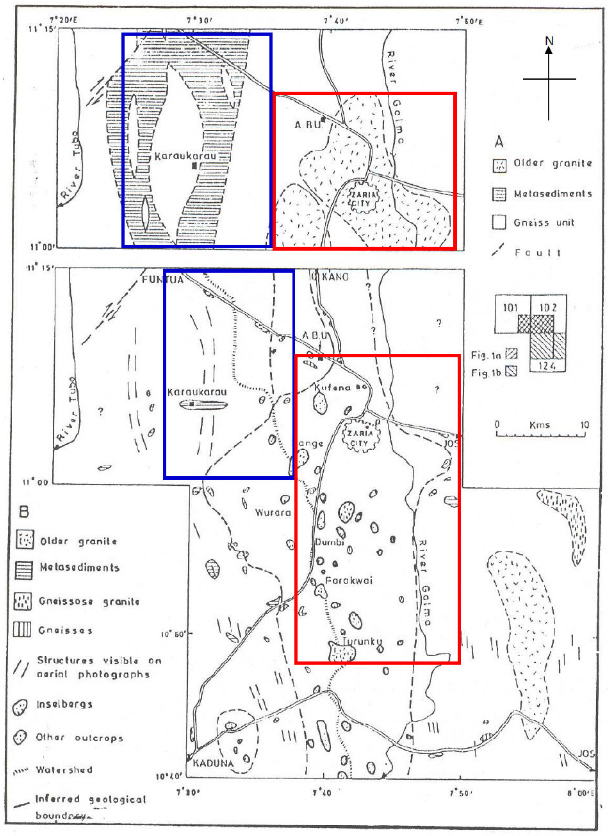

Fig. 2 Geological map of Zaria Batholith and its surroundings, with difference in lithologies indicated with rectangle Map obtains from Geology Department A. B. U. Zaria

III. GEOLOGY OF THE AREA

The older granite outcrops in the vicinity of Zaria are exposures of a syntectonics to late-tectonic granite batholiths which intruded a crystalline gneissic basement during the Pan-African Orogeny. This batholith is a north-south oriented body, about 90 x 22 km, extending from Zaria southward to the vicinity of Kaduna. The Zaria granite batholith belongs to a suite of syn and late tectonic granites and granodiorites that marked the intrusive phase of the late Precambrian to early Palaeozoic Pan-African Orogeny in Nigeria [5]. These granites and granodiorites intruded into low grade meta-sediments and gneisses and were collectively called the "Older granites" to distinguish them from the Mesozoic "Younger Granite" of the Jos plateau and surrounding areas [3]. McCurry's work was based mainly on Photogeological interpretation, supported by selected ground traverses. She distinguished three principal units in the area, namely gneisses, considered to have been metamorphosed more than 2,000 million years ago. The granite batholith (a large, deep-seated intrusive mass) extending northwards and southwards from Zaria, has in fact a western platform, up to 8 km wide, devoid of any inselberg or fresh outcrop more than 4 m high [7].

IV. METHODOLOGY (DATA ACQUISITION)

During the data acquisition, the geophones where placed at 1 m interval, and a variable offset of 1 and 10 m was used. After each shot, the first receiver close to the shot was removed and placed 1 m after the last receiver. The connections to each of the take-outs were swapped in the direction of increasing profile. The energy source was advanced 1 m to take the place of the first receiver previously removed. When all the connections were completed, the instrument was "armed" ready to record seismic signals. A stack of five shots were fired to generate the seismogram with a record length of 1 s. The principle of the common midpoint method was employed, with 12 fold coverage for the 24 channels digital seismograph used. Fresh rocks samples were knocked off from their parent materials with the aid of a hammer for the purpose of determining their densities. The Global Positioning System (GPS) co-ordinates of the profiles were picked (Table I), for the purpose of producing the 3D surfaces.

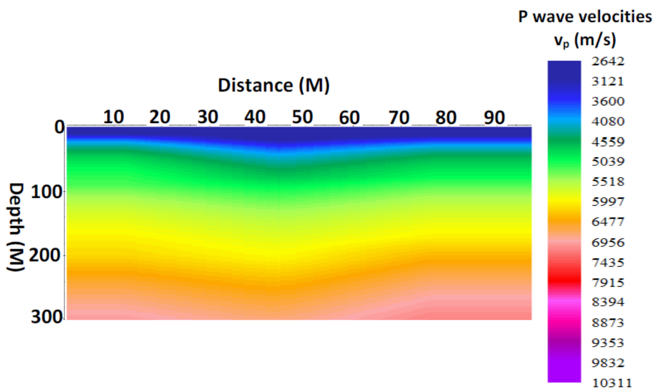

Fig. 3 2D velocity model of profile B-B', at Tuden Wada

V. Data Processing

The data processing started with the importation of the raw seismic data into the interpretational software. The acquisition geometry was edited for any wrong entries during the data acquisition in the field. The gain filter was applied to enhance the amplitude of the weak signal as a result of attenuation by geometrical spreading. Frequency wavenumber *(fk)* filter was applied to remove ground roll and refraction events. The processed data was subjected to semblance analysis to generate a 2D velocity model of the subsurface (Fig. 3). The velocity model was used for dynamic correction and stacking of the common midpoint traces to produce a stacked seismic section. The stacked seismic section was migrated in time to produce a migrated seismic section. The time migrated seismic section was converted into a depth section making use of the initially generated velocity model. The p wave velocities of the various profiles were picked at various depths from the 2D velocity models of each profile (Table II).

TABLE II
P Wave Velocities Estimated for Different Profiles

	P wave velocities (m/s)					
Depth (m)	L-L' Bassawa	N-N' Dumbi	C-C' Kufena	G-G' Kubani	M-M' Tsibirin Sambo	B-B' Tuden-Wada
0	2986	2935.3	3009.9	2562.1	2047.2	2935.3
20	2986	2935.3	4404.6	2562.1	2320.1	3217.9
40	3438	3800.4	5025.6	3421.7	2476.1	4106.4
60	4086	4358.6	5278.1	4027.7	2593.2	4543.8
80	4507	4688.1	5419	4416.4	2688.5	4852.5
100	4803	4912.5	5501	4686.9	2769.8	5187.6
120	5015	5080.5	5675.1	4886	2858.9	5455.3
140	5193	5202.7	5901.4	5038.7	2961.3	5662.1
160	5463	5301.8	6081.3	5169.4	3104.3	5826.5
180	5695	5389.3	6253.7	5353.9	3232.8	5970.6
200	5909	5538.7	6431	5523.7	3375.4	6109.1
220	6096	5674.8	6600.8	5677.8	3516.9	6295.5
240	6264	5819.8	6740.8	5812.9	3631.4	6476.8
260	6412	5903	6864.2	5926.6	3744.9	6638.3
280	6551	5995.4	6978.4	6032.8	3841.8	6784.1
300	6671	6079.9	7059.4	6119	3922.6	6912

TABLE III
Weights and Densities Obtained from the Dry Rock Samples

	Dry weight					
S/N	Profiles	Weight in air (g)	Weight in water (g)	Uptrust (g)	Relative density	Density (kg/m^3)
1	Tsibirin Sambo M-M'	1017	570	447	2.2751	2275.1
2	Tuden Wada B-B'	290	172	118	2.4576	2457.6
3	Kufena C-C'	310	185	125	2.48	2480
4	Bassawa L-L'	164	94	70	2.3428	2342.8
5	Dumbi N-N'	90	55	35	2.5714	2571.4
6	Kubani G-G'	456	260	196	2.3265	2326.5

TABLE IV
Weights and Densities Obtained from the Wet Rock Samples After Soaking For More Than 24 Hours

	Wet weight					
S/N	Profiles	Weight in air (g)	Weight in water (g)	Uptrust (g)	Relative density	Density (Kg/m^3)
1	Tsibirin Sambo M-M'	1032	570	462	2.2337	2233.7
2	Tuden Wada B-B'	302	177	125	2.416	2416
3	Kufena C-C'	327	192	135	2.4222	2422.2
4	Bassawa L-L'	170	102	68	2.5	2500
5	Dumbi N-N'	95	52	43	2.2093	2209.3
6	Kubani G-G'	466	269	197	2.3654	2365.4

The rock samples that were collected from these profiles were weighed with the Mettler PS15 balance in other to determine their densities. The rock samples were weighed in air to determine their weight in air, W_a, and weighed when totally immersed in water, to determine their weight in water, W_w. And soaked in water for more than 24 hours and reweighed following the previous process of weighing in air, W_a and weight in water, W_w . Equation (1) was then used to compute the relative densities of the rock samples, which was converted to density by adding the relevant unit, Tables III and IV.

$$R.d = \frac{W_a}{W_a - W_w} = \frac{W_a}{Uptrust} \quad (1)$$

where W_a is weight in air, W_w is weight in water and $R.d$ is relative densities.

The values of the dry densities and the wet densities were used to determine the average densities values of the rock materials Table V.

The young's modulus was also calculated to ascertain the elastic parameter of the rock material by making use of (2). The values of the determined Young's Modulus are shown in Table VI. The assumption in (2) used in calculating the Young's modulus is that the value of shear wave velocity is half of the p wave velocity.

$$E = \frac{\rho V_s^2 (3V_p^2 - 4V_s^2)}{(V_p^2 - V_s^2)} \quad (2)$$

The depth at which the fresh basement occurred in the various profiles were identified and correlated in Table II, base on their p wave velocity of ≥ 3000 m/s. This was used to generate Table VII, and plot in Fig. 4, which represent a graph of depth to the fresh basement and thickness of overburden at each profile.

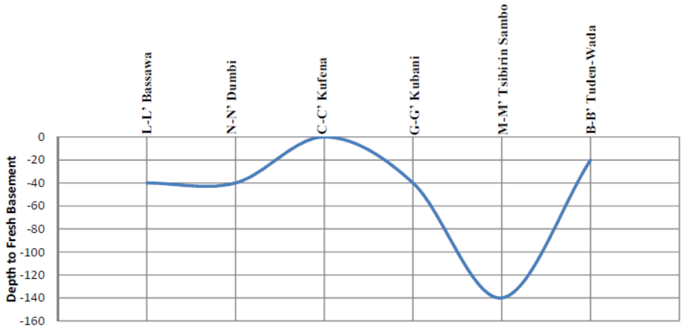

Fig. 4 Topography of the fresh basement using the correlation of velocities from Table II

TABLE V
PROFILE LOCATION, CO-ORDINATE POINTS, P WAVE VELOCITIES AND AVERAGE DENSITIES

S/N	Name of sample	Longitude (Degrees)	Latitude (Degrees)	Determined Surface P wave Velocity (m/s)	Measured Average Surface Density (kg/m^2)
1	Tsibirin Sambo M-M'	7.538000	11.19553	2047.2	2254.4
3	Tuden Wada B-B'	7.718717	11.08167	2935.3	2436.8
4	Kufena C-C'	7.652367	11.08430	3009.9	2451.1
5	Bassawa L-L'	7.675083	11.17390	2986	2421.4
6	Dumbi N-N'	7.646033	10.97565	2935.3	2390.3
7	Kubani G-G'	7.634833	11.14787	2562.1	2346.0

TABLE VI
PROFILE LOCATION, CO-ORDINATE AND YOUNG'S MODULUS

Profiles	Longitude (Degrees)	Latitude (Degrees)	Young's Modulus (P)
M-M' Tsibirin Sambo	7.538000	11.19553	6299023393
B-B' Tuden Wada	7.718717	11.08167	13997035269
C-C' Kufena	7.652367	11.08430	14803890901
L-L 'Bassawa	7.675083	11.17390	14393287945
N-N' Dumbi	7.646033	10.97565	13730236549
G-G' Kubani	7.634833	11.14787	10266681932

TABLE VII
DEPTH OF OCCURRENCE OF THE FRESH BASEMENT AT EACH PROFILE

Profiles	Depth
L-L' Bassawa	-40
N-N' Dumbi	-40
C-C' Kufena	0
G-G' Kubani	-40
M-M' Tsibirin Sambo	-140
B-B' Tuden-Wada	-20

VI. RESULTS

The values of the co-ordinate points in conjunction with the p wave velocities and densities where used to produce 3D surface of Figs. 5 and 6. Fig. 5 showed the distribution of seismic velocities at each profile point taken on the batholith. The result of the seismic velocities distribution showed that the velocities values are higher in the South Eastern part of the batholith where you have more of occurrence of granite, than in the North Western part where you have the occurrence of gneisses, with the highest value occurring at the point where Kufena Hill is located. The result of the density distribution also followed the same trend, as velocity distribution, with the highest density rock occurring in the South Eastern part where Kufena hill is located compared with the North Western part. The values of the Young's modulus, which represent the amount of resistance a rock material will withstand when subjected to a given stress was determine. The co-ordinate point of Table I and the values of Young's modulus of table VI was used to produce the 3D surface (Fig. 7), it also revealed that the rock materials located in the South Eastern part where there are more occurrence of granite has higher values of Young's modulus than the rock material on the North Western zone, where you have occurrence of gneisses. This could be attributed to the fact why the rock materials in the North Western zone are less resistant to weathering and less consolidated, compared with the rock material in the

South Eastern zone, where Kufena Hill stand as the highest point, an indication of high resistant to weathering and consolidation. Plot of the fresh basement topography also confirmed the result stated above, where the basement rock has weathered down to depth of 140 m at Tsibirin Sambo located at the North Western part, and outcropped at Kufena hill up to a height of 689 m above sea level. Analysis of seismic section taken at Kufena Hill Fig. 8 (a), revealed that the section was almost seismically transparent, which is the characteristics of a highly consolidated undisturbed granitic rock [2], while on the other hand the section at Tsibirin Sambo Fig. 8 (b) showed a lot of discontinuous reflection event which is an evidence of high weathering and fracturing, that buttress the earlier results. The satellite image of the area Fig. 9 also revealed that farming activities is more prevalent in the North Western part of the batholith as a result of the presence of thick overburden cover and disperse outcrop, while quarry activity is the other of the day in the South Eastern zone, even at Kufena Hill. A close examination of the geologic map of Fig. 2 made up of sheet 101 sheet 102 and sheet 124, indicates that the South Eastern part outlined with red rectangular lines shows more granitic outcrop, while the North Western part outlined with blue rectangular lines shows presence of occurrence of gneisses and meta-sediments, which goes a long way to complement the results of this experiment.

The difference in lithologies could be attributed geologically to the period of occurrence of the gneisses and granite. The gneisses which form the country rock were first emplaced before the granite, and have experience long exposure to agent of erosion and weathering. The granite which was later emplaced (intruding the gneisses complex) has experienced less period of exposure as a result has experienced less period of weathering.

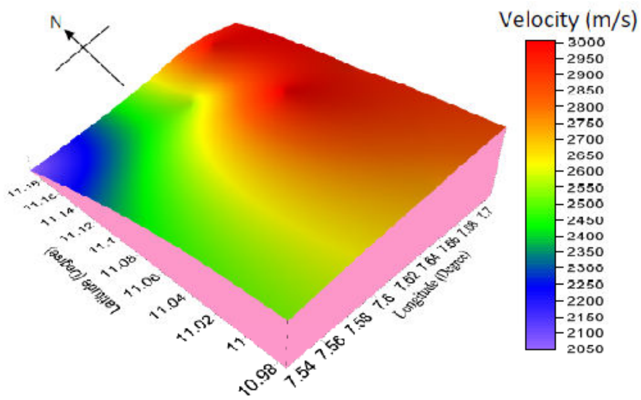

Fig. 5 3D surface of seismic p wave velocities distribution at each profile within the batholiths

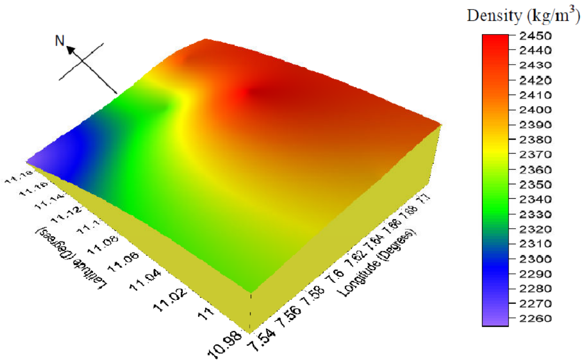

Fig. 6 3D surface of density distribution at each profile within the batholiths

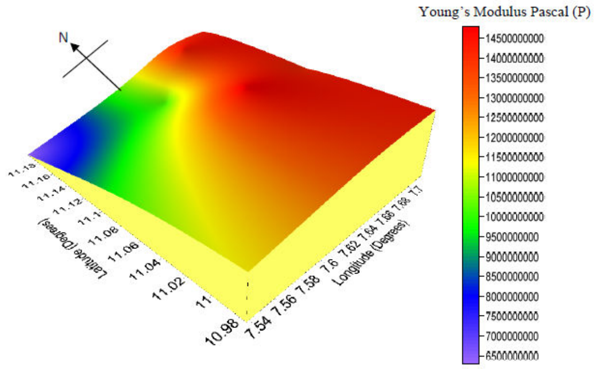

Fig. 7 3D surface of Young's Modulus Values distribution at each profile within the batholiths

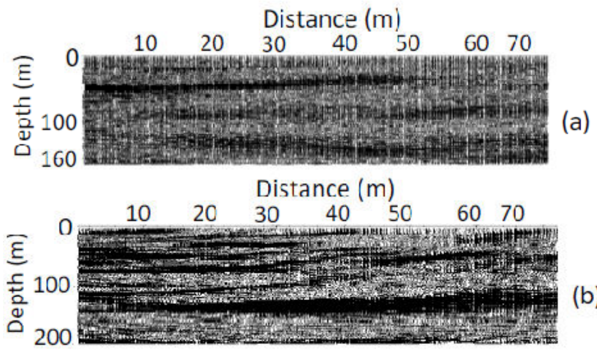

Fig. 8 (a) Seismic section from Kufena Hill (b) Seismic section from Tsibirin Sambo

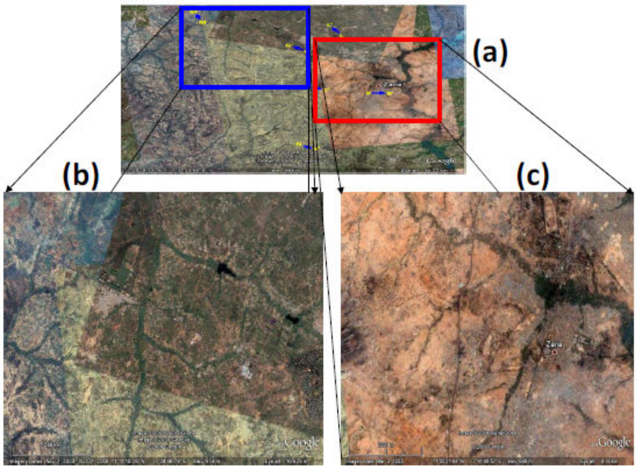

Fig. 9 (a) Survey area (b) Enlarge picture of Tsibirin Sambo, NAPRI, the University farm, University Dam and Bomo Dam(c) Enlarge Picture of Kufena Hill and environs

VII. Conclusion

The results of high resolution seismic reflection survey carried out within the vicinity of the Zaria batholith were conveniently used to identify the two major lithologies that exist between the gneisses that form the country rock into which the granitic batholith intruded. It can be concluded that analysis of high resolution seismic data to extract parameters like velocities, elastic parameters, the basement topography and densities could serve as a very useful tools for the identification of lithologies within a basement complex.

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