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Lithostratigraphy and Characterisation of Paleocene Limestones for Optimal Exploitation (Senegal, West Africa): Comparative Study of the Bandia and Popenguine Quarries

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Abstract

Limestones of different facies in the Senegal basin are most commonly used as aggregates, regardless of their petrographic properties. These differences may influence their behaviour. The aim of this paper is to study the stratigraphy and characterise the limestones of the Bandia and Popenguine quarries. Sampling and geochemical and geotechnical characterisation were carried out on these limestones. The results show the presence of several very different facies in the Paleocene formation. The geochemical study shows that the Bandia limestones (Bd2) have the highest $CaCO_3$ percentages (98.54%) and the highest SiO_2 percentages were recorded in the Popenguine limestones (Pop2). The study also gives MDE values of 22.38 and LA of 22, which are acceptable for use in road construction. It is important to carry out a complete study in order to select the right materials for optimal use.

Keywords

Stratigraphy, Paleocene, Geochemical, Limestone, Bandia, Popenguine

1. Introduction

In Senegal (West Africa), the construction and civil engineering sector is at the centre of development strategies, with the elaboration of sectoral policies backed by massive investments in infrastructure and services. However, the materials used to build these infrastructures and services are diverse (basalt, limestone, quartzite, flint, etc.). The quality of aggregates that meet the specifications of civil engineering is one of the causes of problems in constructions. Limestone, which occurs in various facies in the Senegal Basin, is used as an aggregate by several companies in Senegal. In most cases, these limestones are exploited without taking into account their petrographic characteristics. These differences could affect their durability, their behaviour in relation to water, but also the specific parameters of these aggregates. There is therefore an urgent need to initiate research to better understand the intrinsic properties of limestone aggregates in order to improve their use in the construction sector. The success of infrastructures and services requires good quality aggregates, *i.e.* resistant aggregates complying with the NF P 18545 standard.

The Paleocene in the area presents several layers, especially limestone. During the exploitation process, all limestone layers with different characteristics can be extracted. For a better recognition and exploitation, it is important to know both the lithology and the geotechnical properties of each limestone layer. This is the aim of this study.

2. Geological Setting

2.1. Context Regional

The geology of Senegal is presented in the general context of the MSGBC basin (Mauritania-Senegal-Gambia-Bissau-Conakry). It covers more than three quarters (3:4) of the country's territory [1]. With an area of 340,000 km^2, it is the largest Meso-Cenozoic passive margin basin on the African Atlantic coast. Its maximum width is 550 km at the latitude of Dakar. Wide open to the Atlantic Ocean in the west, it extends for about 1400 km between Cap Blanc in Mauritania and Cap Roxo in south-eastern Guinea-Bissau, through Senegal and the Gambia. It is bounded to the north by the Precambrian Reguibat Ridge in Mauritania, to the south by the Paleozoic Bové Basin in Guinea Bissau and the Léo Man Ridge, and to the east by the Mauritanian chain separating it from the Taoudéni Basin (**Figure 1**).

The MSGBC basin consists of Meso-Cenozoic sedimentary strata underlain by Protero-Paleozoic basement rocks (**Figure 2**).

From a structural point of view, the Thiès region is characterised by the presence of the Diass horst and the Thiès cliff. These structures are of great importance for the stratigraphic recognition of the outcrops of the Senegalese sedimentary basin. It is at the level of the Diass horst that we find the oldest outcrops dating from the Upper Cretaceous (Campanian and Maastrichtian).

For the Paleocene, its base is locally marked by a clast-support type conglomerate unconforming with the Maastrichtian [4]. In the Thièsarea, its top corresponds to the gully unconformity of the Lower Eocene on karstified shell limestone. The limestone-dominated Palaeocene has two transgressive sequences in the region, all of which are now combined in the Cape Verde Group [1]. South of the Diass horst, between Popenguine and Toubab Dialaw, the Lower Paleocene (Danian) comprises a succession of clays, marlstones and marls with

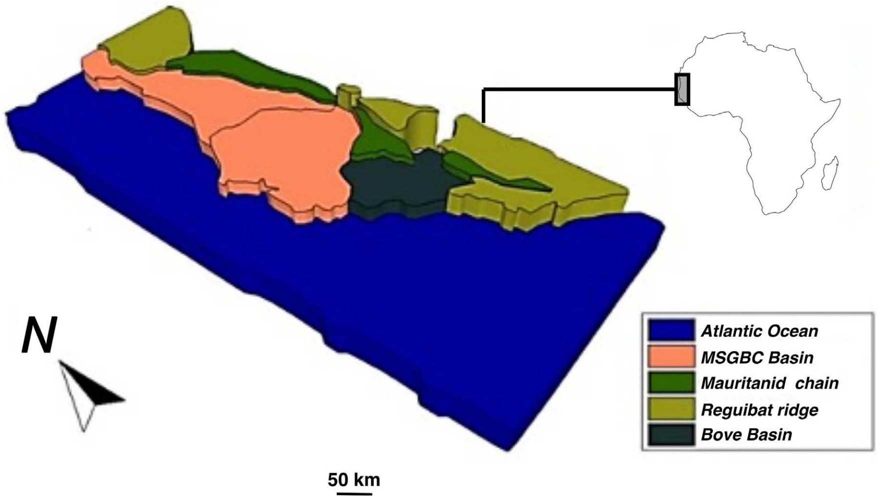

Figure 1. Location of the MSGBC basin [2].

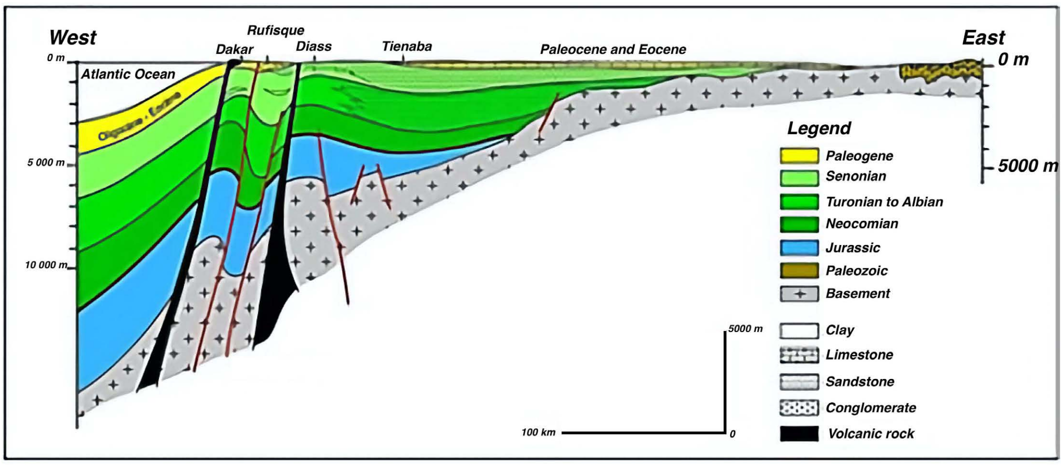

Figure 2. Evolution of the sedimentary basin from west to east ([3]; modified by [1]).

calcite that form the Ndayane Formation [1]. These marlstones form the cliffs of Toubab Dialaw and Ndayane in Popenguine, which have yielded a rich microfauna of planktonic and benthic foraminifera and ostracodes [5] and [6].

To the north and east of the Diass horst, the Dano-Montian consists of grey cryptocrystalline limestones, dolomitic, beginning with a sandstone shell level with ferruginous, phosphatic and glauconitic grains [7] [8]. Mudstone, wackstone and packstone textures alternate. Early dolomite, syn-sedimentary breccias associated with sedimentary textures characterise the peritidal type of sedimentation. Green algae, benthic foraminifera and molluscs indicate a normal salinity marine environment, probably a bay at the base of the Diass dome. The Upper Paleocene or Thanetian consists of a karstifiedzoogenous limestone facies which is very homogeneous in the Thiès area and forms the Popenguine Formation. The limestones are bioclastic and rich in molluscs (gastropods, nudibranchs, nautilus), echinoderms, bryozoans, rare isolated worms and corals. The packstone texture predominates and the cessation of detrital sedimentation during this phase coincides with the submergence of the Diass horst [8]. The Upper Paleocenelimestones are exposed on both sides of the Diass horst, particularly to the west of the Thiès cliff between Pout, Bandia and Mbour, where the outcrop are more extensive. They are extensively exploited in the quarries of Pout and Bandia by cement factories and as aggregates.

The limestone aggregates from the Bandia quarry have been the subject of several research projects, particularly in the field of geotechnics. According to the research carried out, Bandia limestone aggregates can be used in hydraulic concrete and as fillers in hydrocarbon concrete, as well as in road construction [9] [10]. In addition, several laboratory studies have been carried out to investigate the possibility of using limestone in pavements. Recent studies show that limestone is friable and sensitive to water [11]. However, the bearing index CBR at 95% of the OPM of limestone (219) is much higher than that of silexite (105) and basalt (82), but has low resistance to wear and friction and is very sensitive to water [12]. The aim of this work is to find more resistant limestones for optimal use in construction.

2.2. Paleocene Lithostratigraphy

- **At the Popenguine quarry**, the transgression of the Paleocene over the Maastrichtian is well represented. The Danian is assigned to the Ndayane Formation. At the quarry, it corresponds to limestones with marly joints (**Figure 3**). The Maastrichtian is a clast-supported conglomerate. The clasts are calcareous sandstones.

The greyish limestone beds show the first phases of marine transgression from the Paleocene to the Maastrichtian [4] [6]. This level also shows a hardened surface (0.5 m on average) formed in the context of a low water level with high biological activity (**Figure 4**).

- **At the Bandia quarry**, we observed five levels from bottom to top (**Figure 5**):

1) Level 1—consisting of pulverulent (chalky) limestone, with calcite recrystallizations about 4 to 5 m thick;

2) Level 2—consisting of a layer of sand with limestone nodules. The average thickness of this level is about 1 m;

3) Level 3—consisting of a compact limestone bench 0.5 m thick. It constitutes a reference level throughout the quarry;

4) Level 4—laying on level 3, it consists of a massive limestone containing macrofossils (Gastropods, Lamellibranchs…) with a thickness of about 3 to 4 m;

5) Level 5—consisting of a massive karstified limestone about 1.5 m thick.

Two samples, Bd1 and Bd2, were taken, taking into account the level of the quarry.

Depending on the type of work to be carried out, the limestone used must meet a number of criteria in accordance with very precise standards, which is why geotechnical characterisation is required prior to use.

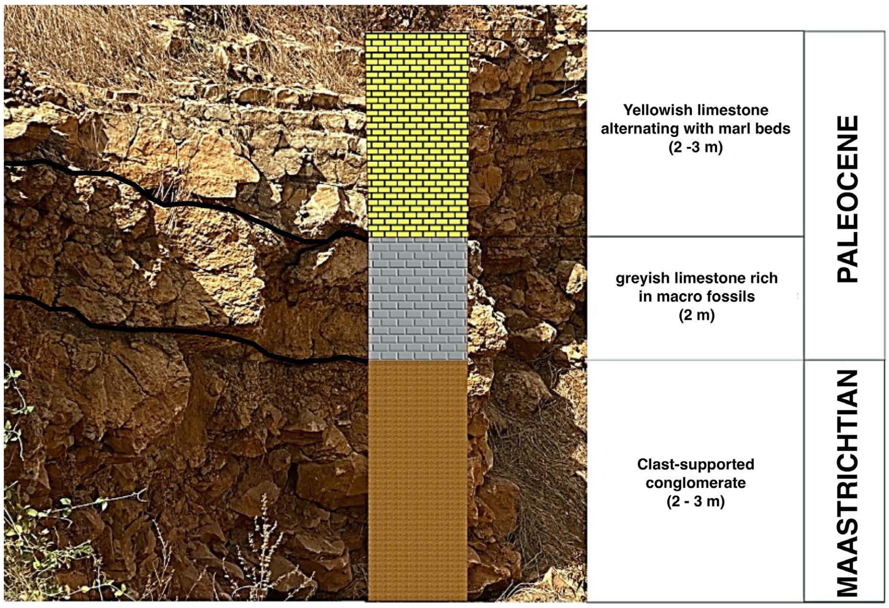

Figure 3. Stratigraphic log of the Popenguine quarry.

Figure 4. Outcrop of greyish limestone rich in bioclasts.

This characterisation consists of determining, by means of standardised laboratory tests, the properties of each granular fraction of a given type of aggregate. The set of values obtained for the geometric, physico-chemical and/or mechanical properties of a granular fraction constitutes its identity.

3. Material and Methods

The material used for this study consisted of 04 samples taken from the faces of the Bandia and Popenguine quarries in the Thiès region (**Figure 6**). The samples were then analysed and processed at the geotechnical laboratory of the Institute of Earth Sciences of the Cheikh Anta Diop University in Dakar, in order to carry out a geotechnical characterisation for their use as aggregates. Chemical analyses were carried out at the GLA laboratory.

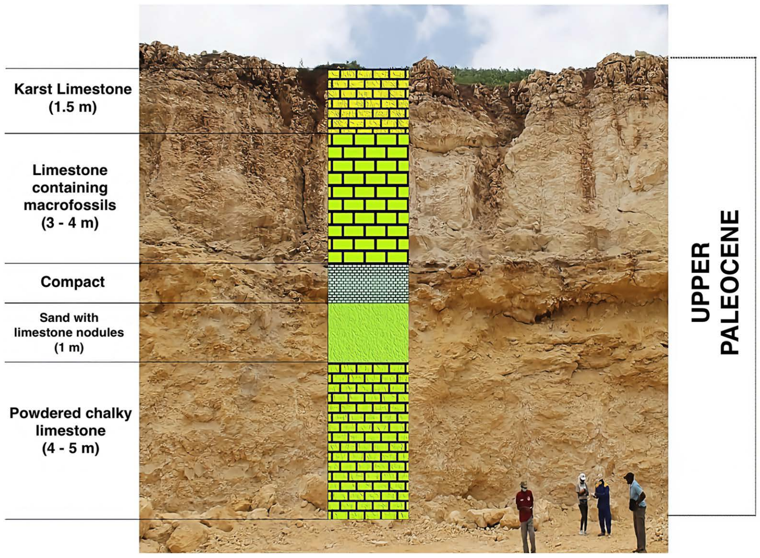

Figure 5. Lithostratigraphy of the Bandia quarry.

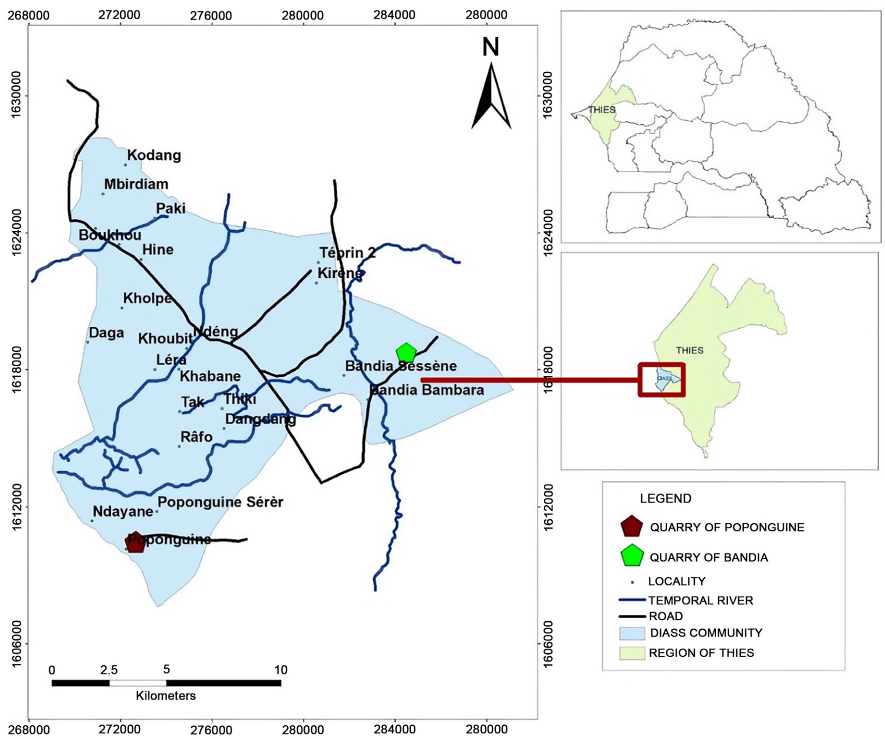

Figure 6. Location of the Bandia and Popenguine quarries [13].

3.1. Determination of SiO_2 and $CaCO_3$ Content

1) SiO_2 *content*: the sample is ground to a powder. Distilled water is then added to 0.5 g of the powdered material, attacked with 20 ml of concentrated 37% hydrochloric acid and placed on a hot plate until dry. It is then treated a second time with 20 ml of concentrated 37% hydrochloric acid and left for 24 hours. The solution is then filtered and the remaining material is placed in an empty crucible of known mass. The assembly (crucible + material) is placed in

an oven at 900˚C for 4 hours in order to eliminate all the constituents of the material except the SiO_2. On leaving the furnace, the mass of SiO_2 is weighed to determine the percentage. This analysis is repeated 3 times for each sample to obtain more accurate measurements.

2) $CaCO_3$ content: Crush the material to a powder. An initial mass M1 (80 g) is weighed and reacted with hydrochloric acid until no effervescence is observed. Then distilled water is added and the solution is filtered. The mass M2 remaining in the filter is collected to determine the percentage of $CaCO_3$.

3.2. Geotechnical Identification Tests

These identification tests are of two types: physical and mechanical.

1) Physical tests

The aggregate identification tests performed include particle size analysis, kurtosis coefficient measurement, true density and bulk density measurements [14] [15]. These tests are carried out according to the following standards: NF EN ISO 17892-4, NF EN 933-3, NF EN ISO 17892-3 and NF EN ISO 17892-2.

These tests are carried out on the following grain sizes:

- 3/8 and 8/16 mm for Pop1 and Pop2 limestone aggregates from the Popenguine quarry;
- 3/8 and 5/15 mm for Bd1 and Bd2 limestone aggregates from the Bandia quarry.

2) Mechanical tests

These tests evaluate these limestones for fragmentation resistance using the Los Angeles (LA with standard NF EN 1097-2 test and wear resistance using the Micro Deval test in the presence of water (MDE) according to standard NF EN 1097-2.

4. Results

4.1. Chemical Characterisation

The results of the chemical analyses are given in **Table 1**. It shows the percentages by weight of $CaCO_3$ and SiO_2 of the limestones sampled at Bandia and Popenguine.

The results of the chemical analyses show that the limestone from both quarries is pure, with higher silica content in the Popenguine sector. However, the Bd2 limestone has a higher percentage of $CaCO_3$ with a value of 98.54%. It also has the lowest percentage of silica with 1.46%. It should also be noted that sample Pop2 has the lowest $CaCO_3$ values with 76.8% and the highest SiO_2 values. This difference could be explained by the paleogeographical conditions of the sediments during the Danian, Selandian and Thanetian; in particular, a transgression-regression cycle was noted during the Paleocene in the Senegal Basin.

4.2. Geotechnical Characterisation

Once the geochemical characterisation is complete, the Popenguine and

Table 1. $CaCO_3$ and SiO_2 percentages by weight of samples.

Samples	%$CaCO_3$	%SiO_2
Pop1	91.93	3.88
Pop2	76.8	4.46
Bd1	81.59	2.7
Bd2	98.54	1.46

Bandialimestones will be subjected to geotechnical testing. These tests include particle size analysis, density determination (MVA and MVR), kurtosis coefficient (A), fragmentation resistance (LA) and abrasion resistance (MDE).

The results of the tests on the Popenguine and Bandialimestones are given in Table 2.

Table 2 shows the intrinsic parameters of the Popenguine and Bandialimestones. From a geometrical point of view, it shows a very flattened shape for the 3/8 classes of Popenguinelimestones, this shape becomes more conformable for the 8/16 classes. For the Bandialimestones, the shape is acceptable. This flattened shape is probably due to the manual crushing of these Popenguinelimestones.

These limestones have similar densities of the order of 2.5, except for sample Bd2 which has a very high density of 3.08 due to the shells present in the rock.

The resistance to fragmentation of the limestones is of the same order of magnitude, except for the limestone of Bd1, which is not resistant to fragmentation. Furthermore, the Pop1 and Bd1 limestones have a low resistance to abrasion, whereas the Pop2 limestone is more resistant to abrasion.

Among these aggregates, Pop2 limestone has the best characteristics. This is due to the large amount of silica (4.46%) present in the rock.

However, Figure 7 gives a summary of the choice of sampling and the intrinsic characteristics of the limestone materials.

The percentages of the chemical analyses but also the geotechnical tests show that the limestone formations are diverse and varied. However, the percentage of carbonate plays an important role in the physical and mechanical properties. This allows a good choice to be made on the sampling and the possibilities of using these materials. This Figure 7 also shows that sample Pop2 has the best characteristics with a $CaCO_3$ content of 91.93% and LA values of 22 and MDE of 22.38 giving it the quality of an A code aggregate. Hence a comparative study for the choice of the best quarry is important.

5. Conclusion

The Senegalese sedimentary basin is characterised by several phases of marine transgression and regression following the opening of the Atlantic Ocean in the Triassic. The stratigraphic and biostratigraphic studies have helped to define the geological context and to understand the geometry of the sedimentary formations in the study area. The rocks of these formations are the most commonly used building materials. The lithostratigraphic study and the characterisation of

Table 2. Intrinsic parameters of the Popenguine and Bandia limestones.

Samples	Granular class	MVA (g/cm^3)	MVR (g/cm^3)	A (%)	LA (%)	MDE (%)
Pop1	3/8	1.29	2.47	51.6	28.42	44.6
	8/16	1.37	2.48	9.2		
Pop2	3/8	1.22	2.54	49.36	22.38	22
	8/16	1.35	2.61	9.32		
Bd1	3/8	1.23	2.5	4.042	55.3	57
	5/15	1.25	2.33	8.62		
Bd2	5/15	1.28	3.08	13.4	28.6	-

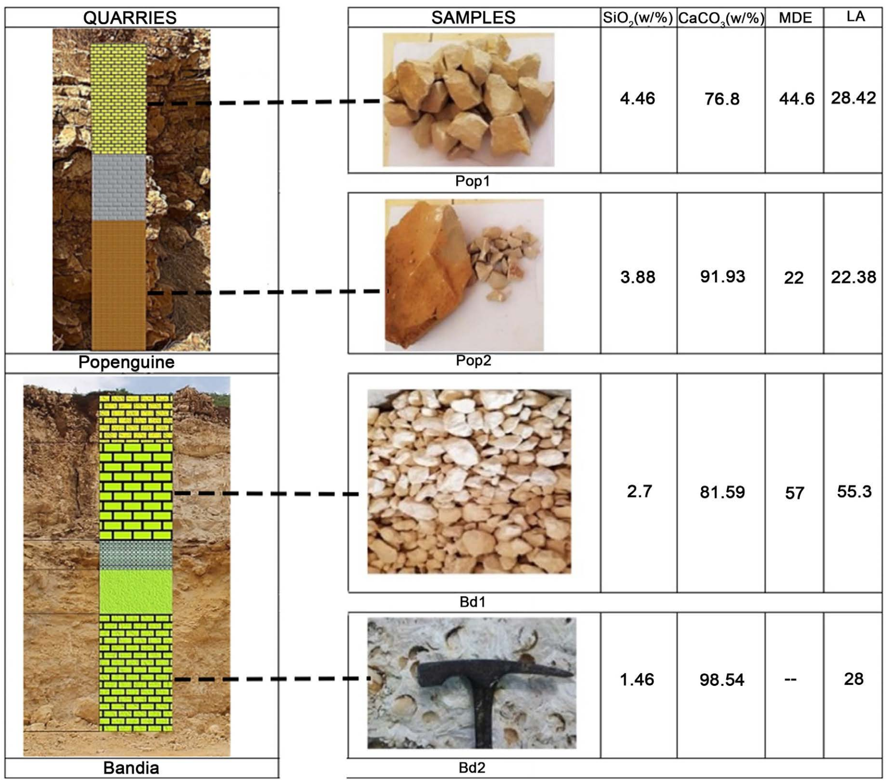

Figure 7. Synthesis of the lithology and intrinsic characteristics of the Bandia and Popenguine limestones sampled.

the Bandia and Popenguine limestones show that there is a diversity of materials at quarry level, often mixed at the time of crushing. These materials have a variety of intrinsic characteristics. The study of the latter has identified several facies that can be used in different ways in the construction sector. The Popenguine quarry has better geotechnical specifications. Its aggregates can be used in several construction applications.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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