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# Geological and Chemical Characteristics of Malbaza Limestone and Implications for Cement Manufacturing

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**ABSTRACT:**

This article presents a geological and chemical study of the limestone mined in the Karni-Ouest quarry in Malbaza (Niger), with the aim of evaluating their suitability for the production of Portland cement. The results show that these limestones, of Paleocene-Ypresian age and belonging to the Garadaoua Formation, have a $CaCO_3$ content of between 72% and 83.5%, which makes them generally compliant with industrial requirements. However, a significant heterogeneity in silica ($SiO_2$) requires selective extraction and controlled mixing with other raw materials (clay, sand) to stabilize the composition of the cru. The article also highlights the transition of the Malbaza Cement Company (MCC) from a non-integral model (import of clinker) to integral production, conditioned by better geological monitoring and rigorous quality control.

**Keywords:** Limestone, Portland Cement, Ader Doutchi, Malbaza Cement Company Malbaza.

## 1 INTRODUCTION

Niger has a variety of mineral resources, including limestone deposits that have been exploited for several decades in Malbaza for cement production. Historically, the Nigerien Cement Company (SNC), which has now become Malbaza Cement Campany (MCC SA), produced cement from limestone extracted from the Karni-Ouest quarry. Despite large reserves, domestic production capacity remains limited, forcing the country to import nearly 80% of its cement needs. The rehabilitation of the Malbaza plant aims to increase the annual production capacity to 650,000 tonnes of *cement* per year and a *capacity* of 2000 tonnes per day [13], with the prospect of making Niger a regional exporter. However, the absence of a geological survey dedicated to MCC leads to often empirical exploitation, without systematic prior geological study. However, the quality of cement depends closely on the petrographic and chemical characteristics of the raw materials, in particular the limestone. The objective of this study is to characterize the limestone facies of the Karni-Ouest quarry in Malbaza, to analyze their chemical composition and to evaluate their suitability for the manufacture of Portland cement.

## 2. General

### 2.1. Geographical framework

The **rural commune** of Malbaza is located in the southwest of Niger, 452 km from Niamey, in the Tahoua region. The relief is dominated by the sandstone plateau of the Ader Doutchi, inclined from the north-east (746 m) to the south-west (300 m) [11]. The climate is Sahelian, with an annual rainfall of between 450 and 600 mm.

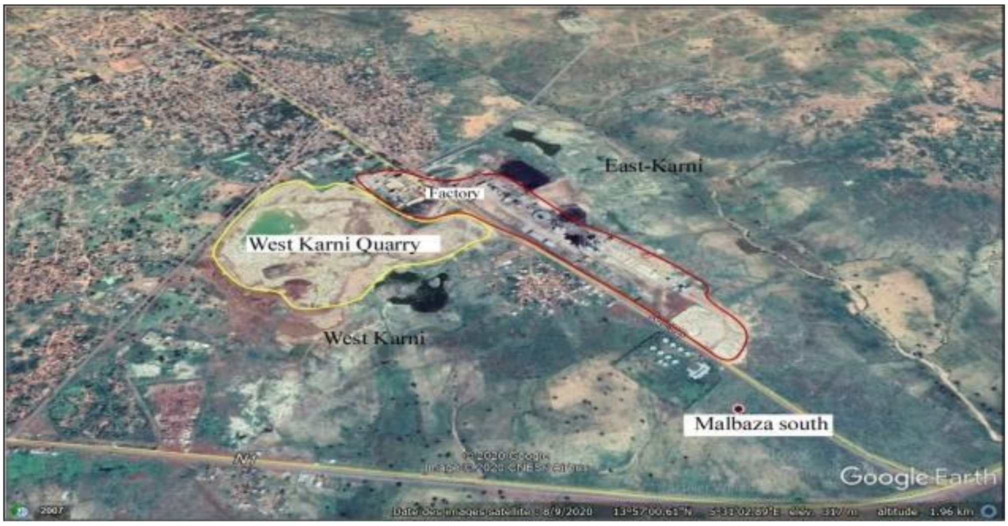


**Figure 1: Map of the location of the Karni West quarry in Malbaza**

**2.2. Geological setting**

Geologically, Malbaza is part of the sub-basin of the Ader Doutchi, itself an integral part of the vast intracratonic basin of the Iullemmeden. This basin has recorded six successive transgressive cycles denoted T1, T2, T3, T4, T5 and T6 from the Late Cretaceous to the Paleogene [7], [9]. The vertical succession of facies, identified for this period, includes from base to summit: calcareous sandstones and gypsum clays, of Lower Turonian-Upper Cenomanian age emplaced during the T1 transgression, gypsiferous limestones and argillites, of Upper Turonian age deposited during the T2 transgression, sandy limestones and marls, of Lower and Middle Senonian age attached to the T3 transgression, siltstones and argillites, of Maastrichtian age, emplaced during the T4 transgression to *Libycoceras ismaeli* and *Laffiteina bibensis*, Paleocene limestones, associated with the *Ranikothalia bermudezi* T5 transgression and Ypresian marls attributed to the T6 transgression to *Lochkartia hamei* [10]. These deposits are divided into two formations: the In Wagar Formation and the Garadaoua Formation [5]. The limestone mined at Malbaza belongs to the Garadaoua Formation of Paleocene-Ypresian age, composed of four members [9] (Figure 2): the Kao Member, made up of the lower papery schists (Lower Paleocene), the Tamaské Member, made up of fossiliferous limestones (Upper Paleocene); the Barmou Member, represented by upper papery shales with palygorskite (Ypresian) and the Keita Member, composed of marls (Ypresian) [9]. These deposits are surmounted by the Continental Terminal (CT1) deposits belonging to the Ader Doutchi formation, of post-Eocene age, composed mainly of ferruginous sandstone [9].

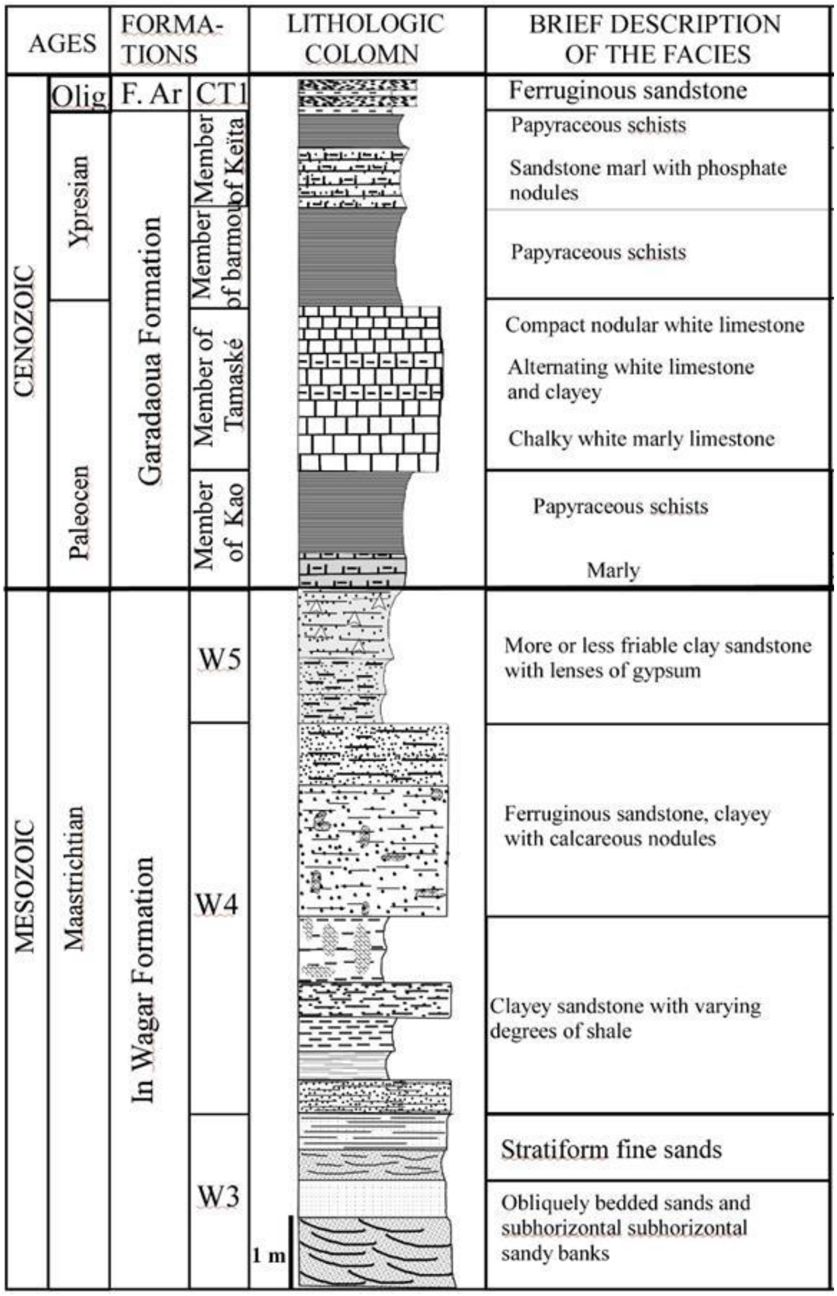


**Figure 2: lithostratigraphy of the Ader Doutchi sub-basin**

## 3. Material and Method

### 3.1. Data and tools

The study is based on a multidisciplinary approach combining documentary sources, satellite imagery and field investigations. The bibliographic data mobilized include university theses, articles and relevant technical reports, making it possible to frame the geological and mining context of the study area. The precise location of the outcrops has been refined using high-resolution images from Google Earth, supplemented by direct observations made in the Karni-West quarry. In the field, samples and surveys were carried out using standardized field geology equipment: GPS for georeferencing, geologist's hammer, pocket magnifying glass, digital camera for visual documentation, as well as labelled bags for sample storage. The laboratory analyses were conducted at the facilities of the Malbaza Cement Company (MCC SA), where specialized equipment such as a jaw crusher, a drum mill, a high-precision analytical balance, a calciner and a ventilated oven were used. The physico-chemical tests used standardized reagents (hydrochloric acid, EDTA, ammonium oxalate, etc.), while the mechanical characteristics of the cement were evaluated using a Vicat apparatus, a universal electronic press and a bending testing machine.

### 3.2. Methodology

The methodology adopted incorporates a logical sequence from the field to the laboratory, then to the industrial evaluation. In the field phase, detailed sedimentological sections were surveyed to characterize the stratigraphy, texture and mineralogical composition of the outcropping formations; Representative samples were taken according to a stratified protocol guaranteeing their fidelity to the geological context. In the laboratory, the samples were subjected to quantitative chemical analyses to determine the contents of major oxides ($CaO$, $SiO_2$, $Al_2O_3$, $Fe_2O_3$), in accordance with internal analytical procedures validated by the MCC. At the same time, an industrial feasibility assessment was carried out by simulating the cement manufacturing process: the extraction of raw materials is currently carried out by ripping, followed by a limestone-clay-sand mixture in an optimised proportion of 80%–16%–4%.

## 4. Results and Discussion

### 4.1. Lithostratigraphic setting and sedimentary context of the Karni-West deposit

The limestone deposit exploited by the Malbaza Cement Campany is located in the Karni-Ouest quarry, located in the sub-basin of the Ader Doutchi, itself integrated into the vast intracratonic basin of the Iullemmeden [10]. The detailed lithostratigraphic analysis of the outcrop reveals a vertical succession of sedimentary formations of Paleocene to post-Eocene ages, testifying to a complex evolution between epicontinental marine and continental environments (Figure 3).

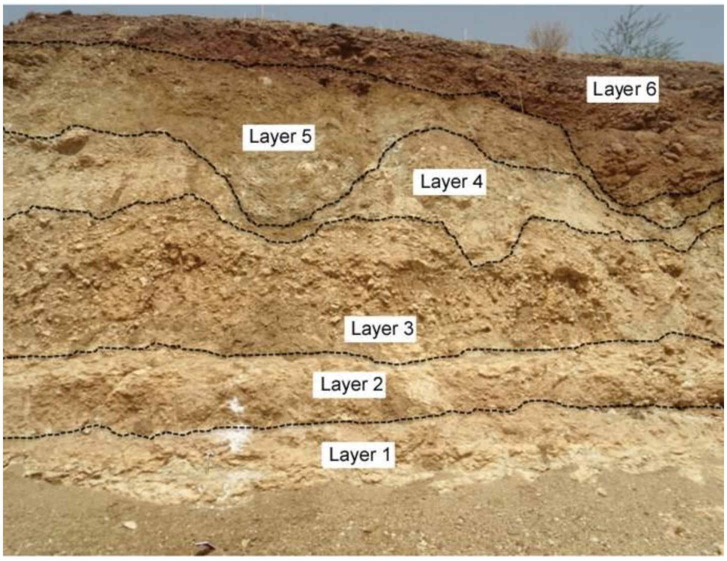


**Figure 3: Limestone outcrop of the Karni-Ouest quarry**

The stratigraphic sequence outcropping in the Karni-West quarry consists of two main formations:

❖ **Garadaoua Formation of Paleocene-Ypresian age** : It constitutes a key marine sedimentary sequence, resting directly on Maastrichtian marls and testifying to a progressive marine transgression through an alternation of fossiliferous limestones and clayey intercalations, rich in macro- and microfauna (sea urchins, bivalves, gastropods and foraminifera). The sequence begins with basal argillites and marls, followed by a thick layer of fissured chalky limestone (1.5 m), fossiliferous and marking the beginning of the Paleocene transgression; the latter is topped by a massive, white and homogeneous bench, of the same thickness, testifying to a stable and energetically well oxygenated deposition phase. Above, a greyish nodulous limestone, partially marly (3 m), reflects an intensification of diagenetic processes and a modulation of sedimentation, before the sequence ends with a laminated clay-limestone facies, transitional and devoid of a marked carbonate structure, prefiguring the end of carbonate sedimentation. This evolution is directly followed by the upper clay formations, represented by the "papery schists" (2 m), grey clays rich in palygorskite, characteristic of a shallow, stable and anoxic marine environment, where the absence of identifiable microfauna signals the definitive halt of carbonate production and the establishment of a clay regime dominated by siliceous mineralogical precipitation, thus marking the transition to the upper Tertiary deposits.

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❖ **Ferruginous formation (Post-Eocene):** Composed of lateritic ferruginous oolitic sandstones (4 m), this unit corresponds to fluvial or alluvial continental deposits, formed after the definitive retreat of the sea. It constitutes the roof of the sequence exploited.

**Table 1:** Lithothermal synthesis of the Karni-West deposit.

| Level | Lithology | Age | Thickness (m) | Repository environment |
|---|---|---|---|---|
| 6 | Oolitic ferruginous sandstone | Post-Eocene | ~4 | Continental (fluvial/alluvial) |
| 5 & 4 | Papery schist (laminated clays) | Ypresian | ~2 | Epicontinental Marine (Deep) |
| 3 | Grey nodulous limestone, partly marly | Paleocene | ~3 | Epicontinental marine (reef/shoreline) |
| 2 | Solid white limestone | Paleocene | ~1.5 | Epicontinental Marine (Platform) |
| 1 | Fossiliferous chalky limestone + clays | Paleocene | ~1.5 | Epicontinental Marine (Transgressive) |

This stratigraphic architecture confirms that the exploitable limestone slice belongs to the Garadaoua formation, of Paleocene-Ypresian age, well known in the Iullemmeden basin [7] [8]. The quality of the limestone used to make cement comes mainly from levels 2 and 3, which are characterized by a high calcium carbonate content and a massive texture favorable to extraction.

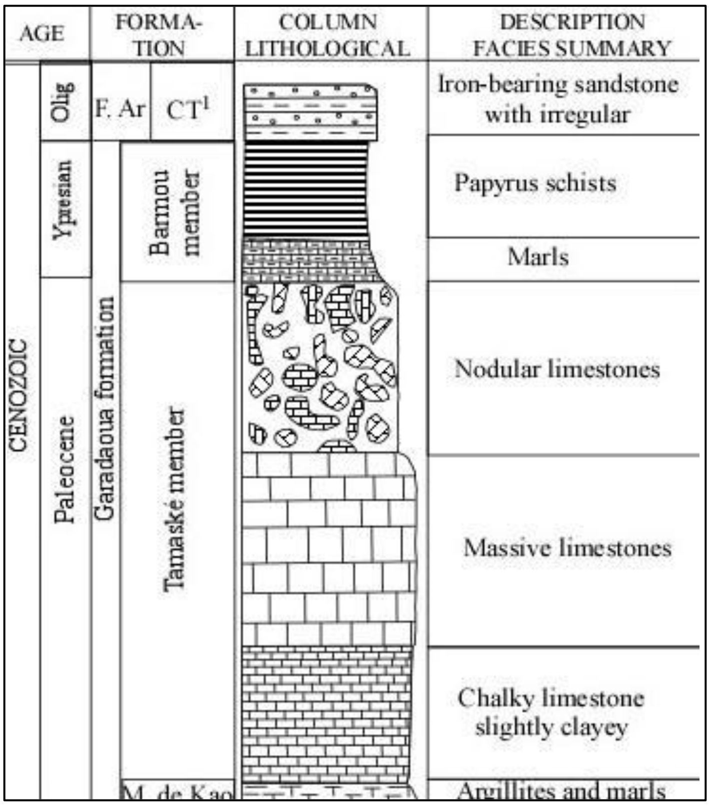


**Figure 4: lithostratigraphic section of Malbaza.**

### 4.2. Chemical characterization of limestone and implications for cement production

The manufacture of artificial Portland cement is essentially based on the chemical quality of the cru, of which limestone is the main constituent. Accurate chemical characterization of raw materials is therefore a fundamental step in ensuring compliance and performance of the final product. In this context, a systematic analysis of the major oxides was carried out on five samples taken at different lithological levels of the Karni-West quarry.

**Table 2:** Chemical composition of limestone samples from the Karni-Ouest quarry

| Oxides / Samples | SiO2 | Tall | Al2O3 | Fe2O3 |
|---|---|---|---|---|
| Sample 1 (limestone) | 1,40 | 53,78 | 0, 96 | 0,8 |
| Sample 2 (limestone) | 4,88 | 51,36 | 1,56 | 1,00 |
| Sample 3 (limestone) | 1,24 | 56,64 | 0,78 | 0,4 |
| Sample 4 (limestone) | 8,47 | 50,86 | 1,56 | 0,8 |
| Sample 5 (shale) | 53,93 | 3,01 | 21,15 | 8,00 |

The results obtained reveal a significant chemical heterogeneity between the limestone facies exploited, although they belong to the same stratigraphic unit (Garadaoua Formation, Paleocene-Ypresian). The content of CaO, a critical oxide in the formation of portlandic silicates (alite and belite) during clinker firing, ranged from 50.86% to 56.64%, with a maximum observed in sample 3. These values correspond to $CaCO_3$ contents between 72% and 83.5%, calculated according to CaO → $CaCO_3$ stoichiometry (factor 1.785), attesting to a limestone that is generally pure and technically suitable for cement production. On the other hand, impurities – mainly represented by $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ – show significant spatial fluctuations. The $SiO_2$ level ranged from 1.24% to 8.47%, with a significant peak in sample 4, while the $Al_2O_3$ and $Fe_2O_3$ contents ranged from 0.78–1.56% and 0.40–1.00%, respectively. These elements, although essential for the formation of melting phases (tricalcium aluminate $C_3A$ and tetracalcium ferrite $C_4AF$), must be present in balanced proportions in order to control the siliceous modulus ($MS = SiO_2 / (Al_2O_3 + Fe_2O_3)$) and to guarantee good reaction kinetics in the furnace. It should be noted that there is a marked contrast between the limestone samples and the shale sample (sample 5), which shows an inverse composition: a very high content of $SiO_2$ (53.93%) and $Al_2O_3$ (21.15%), but almost zero in CaO (3.01%). This opposition underlines the clear transition between the reef or platform carbonate deposits and the palygorskite-rich papery clays of the stratigraphic roof, confirming the existence of a strong vertical lithochemical heterogeneity within the mined sequence (Figure 5).

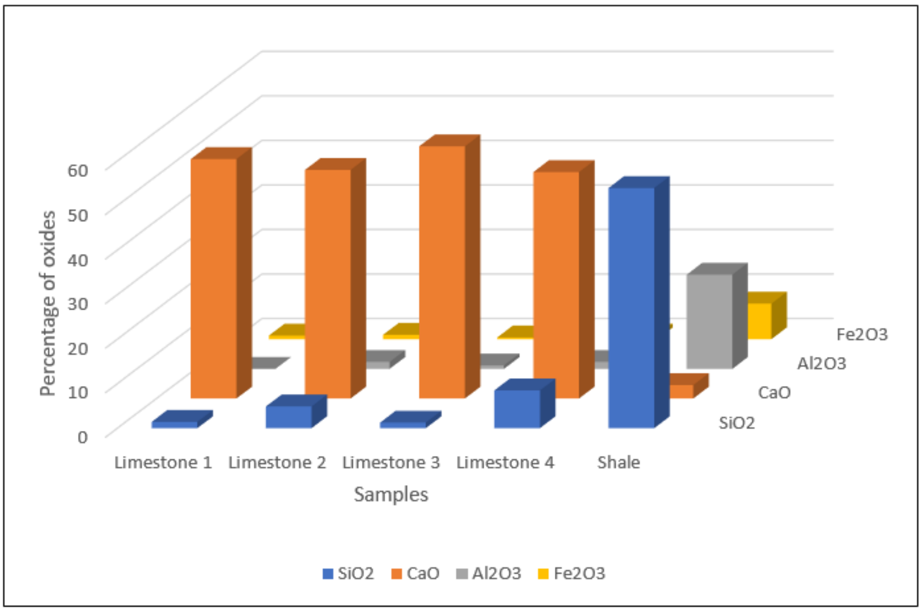


**Figure 5: Variability of major oxides in the materials of the Karni-Ouest quarry.**

Comparison of the data with the technical specifications required by Malbaza Cement Campany (MCC SA) indicates that the Karni-Ouest limestones largely meet the industrial criteria, particularly with regard to the minimum CaO content (<75% required) and the moderate content of aluminous and ferruginous oxides. However, the variability observed, particularly for **$SiO_2$**, implies that the crude mixture cannot be carried out randomly. Selective extraction by lithological level, followed by a precise dosage of the raw materials (limestone, clay, sand), is essential to homogenize the raw material and stabilize the particle size and chemical modules (siliceous module, aluminous module, saturation factor).

**Table 3: Raw Material Specification Sheet**

| Elements | Materials | | | |
|---|---|---|---|---|
| | Limestone | Clay | Sand | Gypsum |
| SiO2% | 5 to 15 | 20 to 35 | >85 | Gypsum Purity >80% |
| Al2O3 % | 1 to 5 | 1 to 12 | 1 to 5 | |
| Fe2O3% | 1 to 4 | 1 to 5 | 1 to 4 | |
| CaO % | <75 | 50 to 65 | 1 to 5 | |

### 4.3. Cement manufacturing process in Malbaza

In 2014, when the company was still called Nouvelle Cimenterie du Niger (NCN), the cement manufacturing process was inspired by the classic dry process, but with a major strategic adaptation: the elimination of the raw firing stage. This decision, dictated by economic and energy constraints, was intended to circumvent the prohibitive costs associated with the operation of the rotary kiln, whose energy consumption represented a structural brake on full production. Faced with this reality, the NCN adopted a **non-integral** production model, based on the import of clinker, mainly from Togo, which it then crushed on site with gypsum (up to 5%) and, if necessary, the addition of limestone to adjust the final composition. This model, although dependent on import flows, has made it possible to maintain local production of artificial Portland cement (CEM I) in accordance with AFNOR standards, while optimizing available resources and preserving the operational viability of the plant in a constrained energy context.

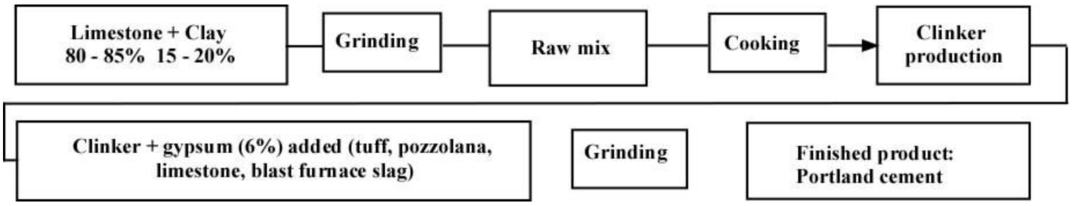


**Figure 6: Diagram of the Portland cement production line in integral chain**

Currently, the Malbaza Cement Company (MCC) operates in a complete chain (Figure 7), marking a crucial step in the autonomy and control of the manufacturing process. The cement produced is Artificial **Portland Cement (CEM I),** composed of 95% clinker and 5% gypsum, the latter being added to regulate the setting time. This integrated configuration, from raw material extraction to cooking, grinding and packaging, allows full control over the quality of the final product. Despite the challenges of energy availability and supply stability, MCC implements a rigorous system of quality controls, both chemical and physical, at every step of the process. These measurements, carried out according to standardized protocols, guarantee the compliance of the cement with the strict requirements of **AFNOR** standards, thus ensuring optimal mechanical performance, increased durability and reliable traceability. This high level of technical mastery positions MCC as a key player in the national strategy of industrial sovereignty and regional export of cement.

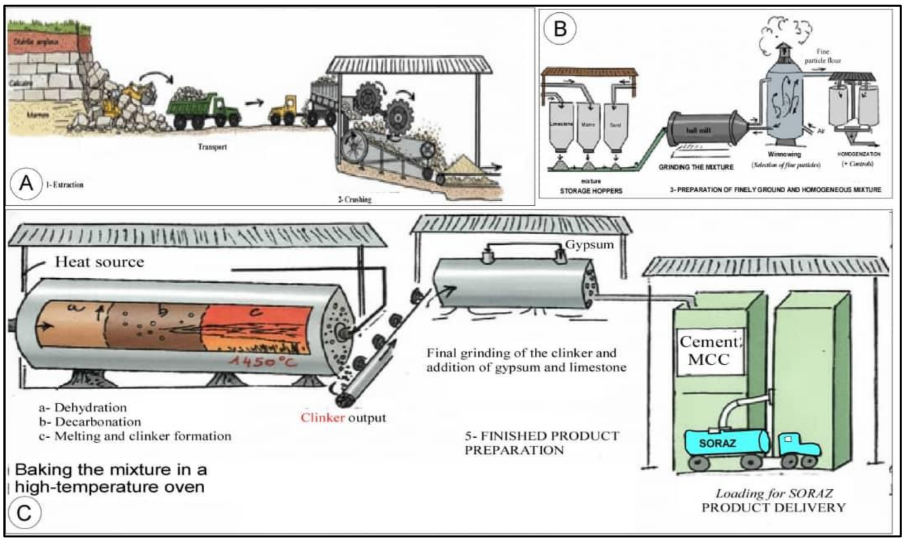


**Figure 7: Cement production line at MCC**

## 5.Discussion

This study on the limestones of Karni-Ouest (Malbaza, Niger) confirms that the quality of the raw materials for the manufacture of cement depends intrinsically on their geological context and their chemical composition, as pointed out [12] in their work on the stability of the cementitious phases. The CaO (48.9–56.6%) and $CaCO_3$ (72–83.5%) concentrations observed at Malbaza are comparable to those of the mined deposits in Nigeria, where [1] reported values of 78–92% $CaCO_3$, although the latter often have more undesirable trace elements. In Togo, Tabligbo limestone, the main current source of clinker for Niger, has a higher purity ($CaCO_3$ >85%), according to [4], which historically justifies import. However, our results show that, with selective extraction based on a good lithostratigraphic knowledge, an approach advocated by [8], for the Iullemmeden basin, Nigerien limestones can achieve an equivalent technological quality. This need for control is reinforced by the marked heterogeneity in $SiO_2$ (1.24–8.47%), a challenge also encountered in the Algerian quarries of Béjaïa, where [3] have implemented precise limestone-clay mixtures to stabilize the cru. In Europe, strict standards (AFNOR, DIN) require a controlled silica modulus, a constraint similar to that noted here, where adjustments by adding sand or clay (proportion 80-16-4) are essential, as demonstrated [2] in Spain. Even in high-producing countries such as India, [14] have shown that moderately impure limestones ($CaCO_3$ ~70%) can be used through fine dosing, a strategy that is quite applicable to Malbaza. The evolution of MCC towards a full chain, although facing energy challenges, follows a global trend towards industrial autonomy, as in the United States where [6] documented the systematic integration of quarry geology to optimize production. The current absence of a geological survey dedicated to MCC is therefore a major obstacle, even though the international scientific literature [15] in Australia [7] in West Africa) insists on the fundamental link between rigorous geological monitoring and sustainable industrial performance.

## 6. Conclusion

This study carried out on the Karni-Ouest limestone deposit in Malbaza made it possible to characterize the geological, lithostratigraphic and chemical aspects of the materials used in the manufacture of cement. The mined limestones belong to the Garadaoua Formation of Paleocene-Ypresian age, integrated into the Ader Doutchi sub-basin, and are in the form of four distinct levels, whose massive and nodulous facies are the most suitable for industrial exploitation. Chemical analyses reveal a CaO content ranging from 48.90% to 56.64%, corresponding to a $CaCO_3$ between 72% and 83.5%, indicating a good purity limestone, broadly in line with the specifications for the production of Portland cement (CEM I). However, a significant lithochemical heterogeneity, particularly in $SiO_2$ (1.24–8.47%), requires selective extraction and controlled mixing of raw materials to ensure the stability of the cru. Currently, the Malbaza Cement Company (MCC) operates in a non-integral chain, based on the import of clinker (mainly from Togo) crushed with 5% gypsum, but with the prospect of switching to integrated production. Rigorous quality controls guarantee that the final product complies with AFNOR standards.

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Conflict of Interest Statement: All authors have nothing else to disclose.