**UTILIZATION OF LOCAL MATERIALS IN ROAD CONSTRUCTION IN THE SAHARA AND SELECTION CRITERIA**

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**SUMMARY**

The climate of the dry regions of the Sahara allows a wide range of materials that would be prohibited in humid to sub-humid zones of the Mediterranean regions to be used in road construction. Their deposition is guided by local geological and geomorphological conditions. The specifications for their use in road engineering take into account the geotechnical criteria relevant to climatic zonality. The materials most commonly used include the following:

- *Dune sands* that cover an immense area that is the large Eastern and Western Ergs; These sands are either predominantly siliceous or gypsic, or arenitic, depending on the regional geology.

- *The granitic or gneissic arena sands* that cover a large part of the Hoggar desert. These are the product of exogenous *in situ* weathering of the upper part of the granitic or gneissic massif of the schistose crystalline massif.

- *The weathered basalts* that split either in boulders or in gravel with continuous grading over aweathering thickness of 1 to 2 meters. They are associated with basalt or andesite extrusion zones of the Hoggar. These gravel are frequently used in road pavements in the Tamanrasset region.

- *The Zarzanitine Trias series clays* in the region of *In Aménas* that split into sand or gravel on extraction. These are very hard and compact rock.

- *The plateau ungraded material (plateau run).* Large surfaces one covered by sand-clay-gravel surface formations.

- *The calcareous, gypsic or mixed incrustation* commonly known as tuffs covering large areas both in the region of the Saharan Atlas and in the Saharan flats.

Using case studies of major Saharan roadways and research studies carried out in different laboratories including that of the University of Algiers, we hereby present the allowable specifications relative to their use in the field of roads as well as several examples of damage that have appeared in certain road construction projects in the past thirty years.

*Key words: Road construction in the Sahara – dune sands – granitic arena sands – modified basalts – clays of the Zarzaitine series – plateau rubble – calcareous incrustations*

## 1. INTRODUCTION

The development of roadway and airport infrastructures in the years 1955/56 in ALGERIA created a significant need for road-building materials. For Northern Algeria, the engineers of that era solved the problem of selection of materials by drawing upon American and European methods and techniques. Thus, the uneven terrain and the mean annual pluviometry greater than 600 mm made it possible to use local materials such as wadi run (ungraded maerial) and crushed rock. For the dry regions of Northern Algeria (pluviometry between 100 and 350 mm) and the Saharan zones (pluviometry < 100 mm), the excessive transport distances and the reduced means forced the engineers to use either calcareous, gypsic or mixed incrustations or plateau rubble, granitic arenas, or sometimes even clays of varying hardness. Still guided by the methods and specifications of temperate countries, the engineers of that era sometimes incorrectly used these local materials. The first tuffs roads had base courses of a thickness of 40 to 50 cm. Considering the traffic of the era, these dimensions were exaggerated. Other inappropriate materials were used, the workyards were protracted and certain roads quickly deteriorated.

Gradually, engineers such as FENZY and FONKENEL became interested in pedology, geology and the geotechnology of these materials and in the adaptation of conventional methods to arid and semi-arid zones. The thickness of the roads along with the unsatisfactory results started to diminish. Geotechnical and geological analysis of the different road transport routes made it possible to inventory a wide range of Saharan materials. The following may be mentioned among the major roadways studied between 1956 and 1960:

| | |
|---|---|
| Ghardaia – El Golea | : 270 Km |
| Ghardaia – Ouargla | : 200 Km |
| Ouargla – Hassi Messaoud | : 100 Km |
| Fort Allemand – Edjele | : 140 Km |
| Tougourt – Square Bresson | : 80 Km |
| Square Bresson – Ouargla | : 160 Km |
| El-Golea – In Salah | : 420 Km |

So, in 1965, at the Roads Congress that took place at Beni-Abbes (ALGERIA), these Saharan specifications were created under the direction of Mr FENZY. After this focus, the Algerian LCPC Division engineers initially, and then the engineers of the LNTPB (Algerian Laboratory), refined this technique while conserving the principles acquired prior to 1965. The majority of the materials of the greater South (annual pluviometry < 100 mm), respected these specifications. For the materials of the semi-arid to steppe zones, certain principles such as the "setting phenomenon" of the tuffs required verification in order to arrive at more realistic selection and implementation criteria in the light of modern techniques.

## 2. OVERVIEW – GEOGRAPHICAL AND GEOLOGICAL SUMMARY OF ALGERIA

The terrain of the Maghreb in general and of ALGERIA in particular is characterized by a series of largely East – West oriented secondary mountain ranges separated by depressions of the same orientation where wadis such as Chellif and Soummam run.

These mountains represent the secondary ranges of the Atlas, itself subdivided into the Tell Atlas and the Saharan Atlas. Further to the South, the Saharan flats extend over more than 700 km and are continued by the immense Hoggar range.

## 3. CLIMATOLOGICAL OVERVIEW

The pluviometric map shows decreasing isohyets between the wet coastal zones (annual rainfall > 600 mm) and the arid Saharan zones (H < 100 mm).

Zone I: Humid Mediterranean H > 600 mm
Zone II: Sub-humid Mediterranean 600 mm < H < 350mm
Zone III: Semi-arid or steppe 350 mm < H < 100mm
Zone IV: Arid or desert H < 100 mm

This division is directed East – West by the terrain, but is complicated by the altitude and certain micro-climate corridors.

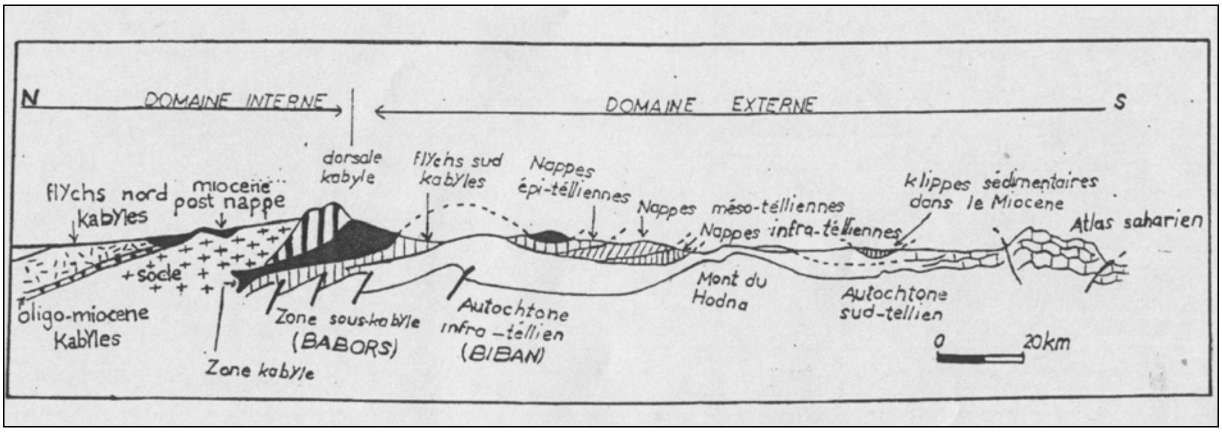


Figure **1 :** Summarized North – South Geological Cross-Section of Algeria

## 4. SAHARAN MATERIALS

Considering several factors, including: the very low precipitation rate of sometimes < 30 mm of rainfall per year, the likewise very low traffic (< 100 HGV / day) and a rather monotone geology (large series of uniform surface formations), the available materials alougth roads have been identified and classified according to the geotechnical criteria that make it possible to use them in different elements of the road pavement. The materials have been classified into three large groups according to grain size distribution (reference range commonly known as Beni Abbes – 1965), cohesion, and skeletal hardness criteria.

1. Materials having a high friction angle also known as skeletal materials similar to the classical materials of the humid regions. These materials must come within the particule size distribution envelopes, the Los Angeles coefficient must be less than 40, and Ip between 6 and 12. It is, moreover, desirable to have a resistance to compression about of 10 to 15 bar. The soils entering into this category are most frequently: the wadi run (ungraded material), the plateau run, the gypso-calcareous gravel and roundstone with gypsic fines.

2. The high cohesion materials that owe their unconfined compression resistance to the presence of calcareous, gypsic and clay fines. The combinations and proportions among these three minerals in the < 0.08 mm part forms a selection criterion for the sub-grades. These are calcareous tuffs, saline gypsic incrustations and other predominantly clay rubbles such as the granitic arenas. While the calcareous tuffs have at times rather course granulometrics of < 20 mm, the gypsic tuffs or gypsic sands more frequently have sand-like granulometrics well above the range, with < 0.08 mm elements exceeding 50%.

3. The intermediate materials: These are materials having an insufficient skeleton with granulometric curves wholly or in part outside the range and an inadequate unconfined compression resistance. These are rubble of any type, poorly graded wherein the combined proportions of the different calcareous, gypsic and clay minerals conform on a case-by-case basis to the conditions of use.

## 5. THE SKELETAL MATERIALS

### 5.1. The Wadi run

There are innumerable small wadis in the dry regions. The rains, being very rare and violent when they do occur, encounter a dry soil that is easily eroded. The strong currents that are created carry significant masses of soil and deposit them according to the laws of sedimentation all along their paths. However, when the channels are sufficiently vast, they contain material that is sometimes more appropriate than the discharge material. They are cleaner and often better graded. They are better suited for the road pavement.

### 5.2. - *The plateau run.*

This is the Hamadas material or the colluvia from slopes. Fragmentation is often due to frost. The thicknesses of the deposits are not generally heavy. Levels can be partially incrusted with limestone or gypsum and at times mixed.

## 6. THE HIGH COHESION MATERIALS

### 6.1. The Tuffs

The tuff incrustations are present in the majority of the Mediterranean basin. They currently occupy the dry climate zones. In ALGERIA, they cover approximately 50% of the Northern area of the country (J.H. DURAND 1959). This is a superficial formation with a pedological origin which develops at the edge of the calcareous or marl massifs of North Africa and the Sahara.

#### 6.1.1. Clarification of the word "tuff":

The Illustrated Petit Larousse (edition 1980) gives the following definition of the word tuff: "A light porous rock formed from cemented volcanic ash (cinerites) or calcareous concretions deposited in springs or in lakes". For the geologist, a more elaborate definition is given by: L. MORET (1962)

"Volcanic tuffs are the products of volcanic ejection, lapillis or ash, stratified by the action of water". "Sedimentary tuffs are irregular or spongiform incrustations at the issue of calcareous springs and which contain numerous moulds of plants and mollusks. When these springs discharge into a lake basin, the limestone precipitates in a fine crystalline powder which is stratified in regular layers. The rock is then more compact than a tuff and is given the name travertine or sinter. "In North Africa the problem is more complex. The formations called "tuffs" are in fact calcareous, gypsum or mixed incrustations; nonetheless, the connection between the tuffs defined by L. MORET (1962) and the incrustations can be made in nature in the form of gradual passage from the one to the other of these formations".

### 6.1.2. Situation and geographic extent of the tuffs

The map according to J. H. DURAND (1959) shows that the calcareous tuffs occupy climatic zones II and III. They exist nonetheless in zone I but in a somewhat differentiated state and in zone IV. They rarely occur in altitude. They are present in the relatively flat basins irrigated by the runoff water from the boundary calcareous massifs. The predominantly calcareous tuffs cover an area of approximately 300,000 $km^2$ in Algeria. The calcareous incrustation tuffs, very extensive in the sub-humid to semi-arid climatic zones of Algeria are pedological formations, the oldest of which date from the Villafranchian or Moulouyen. The dissolved limestone of the mountain massifs is sometimes transported over large distances and deposited in the soils. The limestone concentrates at the surface and forms a carapace of 1 to 2 m in thickness.

The gypsum incrustations are formations similar to the calcareous tuffs. They are very abundant in the arid climatic regions where the gypsum is already present in the old geological formations (cretacean to miopliocene). The fluctuation of the groundwater table as well as evaporation of the capillary fringe result in the deposition of the gypsum. The fragile, easy to extract incrustations are used as a road construction material and are called gypsum sands.

The Constantine lake limes, sometimes incrusted on the surface, are also considered to be tuffs but are such only in their top portions.
The powdery calcareous formations of Alger, also called tuffs, belong to a delta molasse formation of the Astian age

### 6.1.3. Materials selection criteria

The calcareous incrustation tuffs consist of a calcareous crust and a low-lime lower horizon that gradually passes to the incrustation bed. This crust comprises a heavily (90 to 95%) calcareous flagstone 3 to 4 cm in thickness, the rest being essentially quartz and attapulgite. Under the flag, the crust is also essentially calcareous with a higher fibrous clay content in the fine fraction. The calcite grains that comprise this powdery fraction of the incrustation are very fine (1/10 $\mu$ to 10 $\mu$); the amount of these calcareous and clay fines will play a role in the quality of the road material which is the tuff.

Selection criteria connected with the laboratory tests and the *in situ* studies of geological formations must be defined separately for the essentially calcareous materials and for the essentially gypsum materials. A logical deduction must result in the definition of materials selection and utilization criteria wherein the gypsum and the calcite are in somewhat equal proportions.

The CBR taken up at D4 for the steppe to desert regions is in fact an unadapted test because it rains very little. However, these rare, but violent, rainfalls over a very short time (several hours) cause the soil to soak heavily. In addition, suction phenomena maintain the materials under the road in a state of hygrometry, for the winter period, close to the OPM water content. We figure CRR, whether soaked or not, in resistance to unconfined dry compression, because this latter represents an ideal state that is not possible all year long.

Analysis of some fifty samples taken at the time of the reinforcement study of the RN1 between Djelfa and Laghouat (100 Km) has shown that the product ( Ip x $\frac{0.4}{100}$) correlates with the percentage of "carbonate + sulfate" and the CBR soaked up at D4. We indicate that the percentage in sulfate is low (of the order of 0 to 5%).

For a low simplified group index (< 2), the material has CRR > 80% even if the percentage of calcite + gypsum is low < 20%. In order to have a CRR > 80% it is necessary, for heavily carbonated materials ($CaCO_3$ = 60%), to have (Ip x $\frac{0.4}{100}$) < 3. The current material selection criteria are more restrictive; the Ip must be < 13% in zone III and IP < 10 in zone II. The granulometry being defined independently of plasticity, the correlation associated with the CBR is included.

Figure 2 : The Saharan Atlas Landscape: road embankment platy limestone incrustation

Figure 3: Route Nationale [main road] N$^{o}$ 3 at El Oued: base course gypsum sand with good road setting

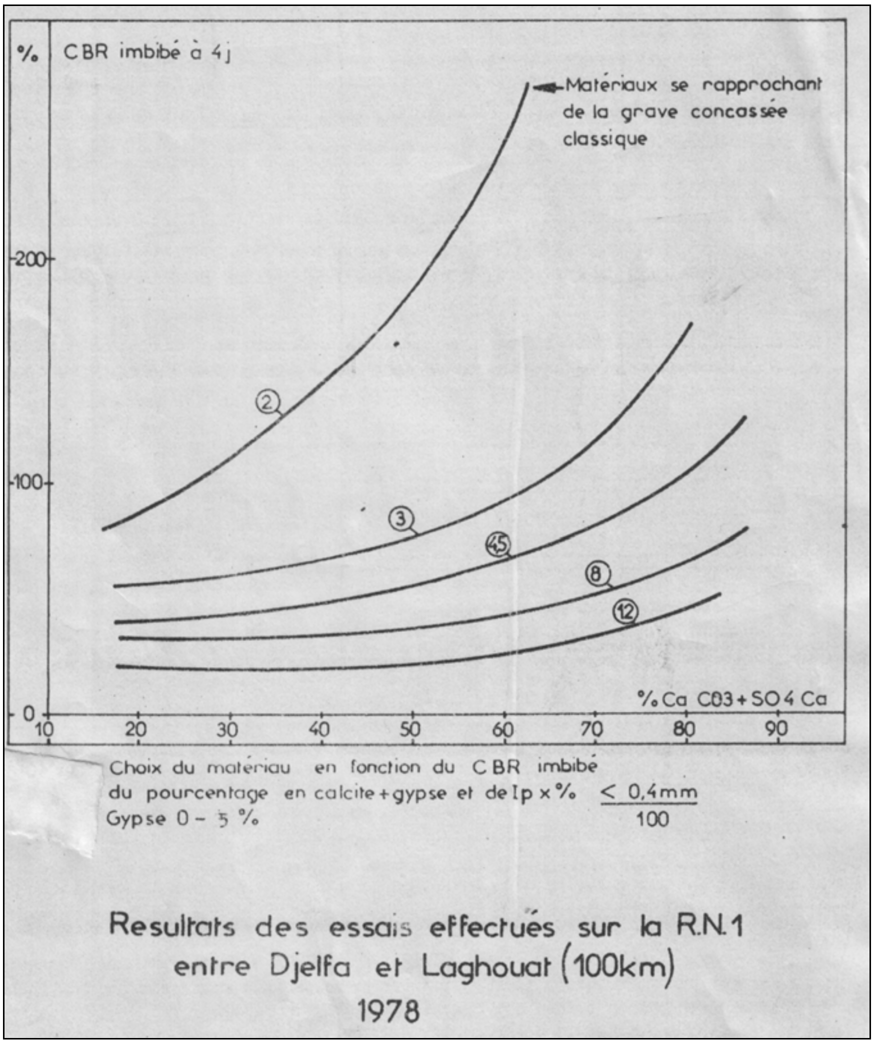


Figure 4: CBR diagram soaked with the % carbonate and sulfate parametered by IP <0.4/100

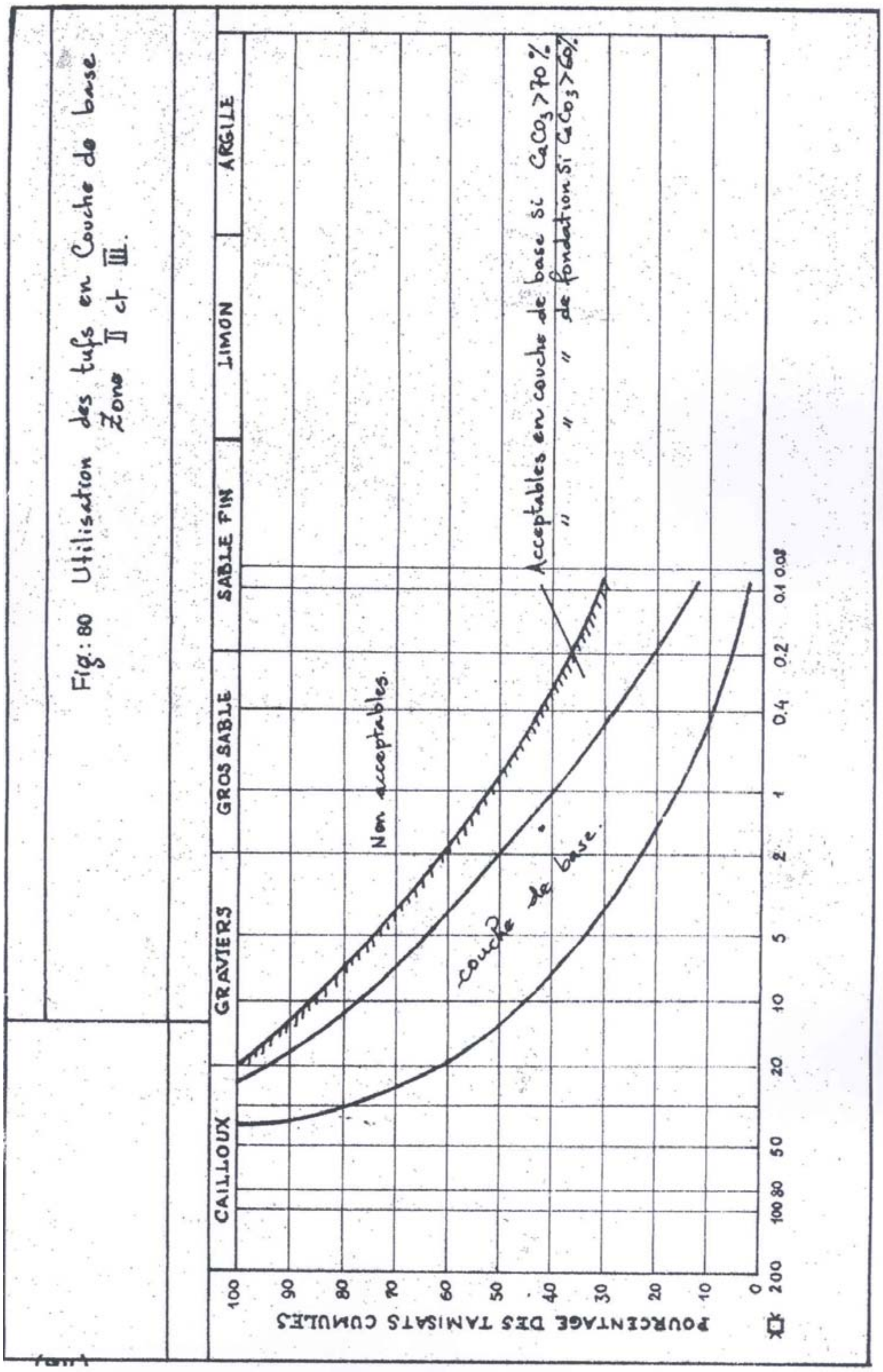


Figure 5: Reference grading range for the calcareous tuffs

Figure 6 : Platy crust and compact flagstone of a calcareous incrustation


Figure 7: BEB compacted calcareous tuff: rafted granules of calcite
and fibrous attapulgite

Figure 8  RN 3: Road pavement made of gypsum sands: degradation by cracking

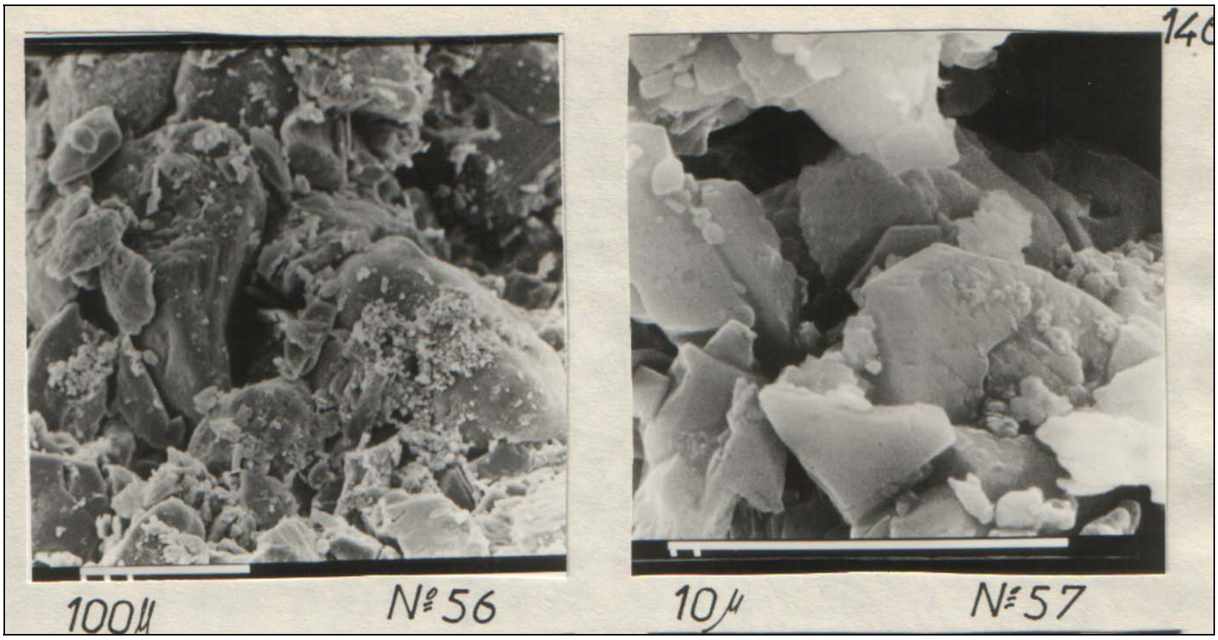


Figure 9 : MEB gypsum tuff, very fine gypsum flakes filling in
the spaces between the coarse grains

### 6.1.4. Selection criteria for roadway gypsum tuffs

The gypsum sands behave like fine sandy materials but have strong characteristics associated with the presence of gypsum and calcite. It is, however, difficult to attribute these strong characteristics (C, φ, CBR) to the mere presence of the gypsum or to the fineness of the material.

It is the contribution of these two phenomena, and only under conditions of dryness, that enable the gypsum sands to acquire strong resistances and low deformability.

Under conditions of water content close to OPM, these materials are hardly different from sands of another mineralogical nature. Their utilization is subject to (sometimes local) conditions of humidity under the road.

1) In zone IV. As the gypsum is not at risk of solubilization, it is the percentage of gypsum + the percentage of calcite which is taken into account: carbonates + sulfates > 70%, Rc must be > 20 bar.
2) In zone III – the gypsum is at risk of solubilizing under the road, the maximum percentage of gypsum tolerated is 5% in the < 1 mm fraction.
3) In zone II – The gypsum is at risk of solubilizing. It is thus not allowed in an untreated base course.
4) The plasticity and granulometry criteria remain the same as for the materials of zone IV, because they are used only in this zone in the base course.

## 7. THE GRANITIC ARENAS

The Hoggar massif is composed almost entirely of very ancient schistose crystalline rock. A product of exogenous and in situ weathering of the upper part of the granitic or gneissic massifs, the sands and arena gravels are road materials of the extreme South of the country. This modification of several meters in depth (up to 10 m) has provided plentiful road construction material. The materials used come from either the weathered cap which gives rise to coarse granular arenas having little cohesion or more cohesive arenas resulting from the mixture of fine rubble and predominantly quartz arenitic sands. This provides coherent arenas with 0/5 mm granulometry. The search for quarries for raod pavements follows an investigation and laboratory testing methodology that is well-known to Algerian engineers and laboratory technicians. Particular mention may be made of the ex-LNTPB at which Mr Domec, an engineer, directed several prospecting teams. In addition, he has established reference ranges for arena materials as well as the majority of materials found on the projection trace. (Fig. 10)

Certain arenas of the Arak – Tamanrasset sector with a 0/5 mm granulometry have given values of 30 bar in unconfined compression.

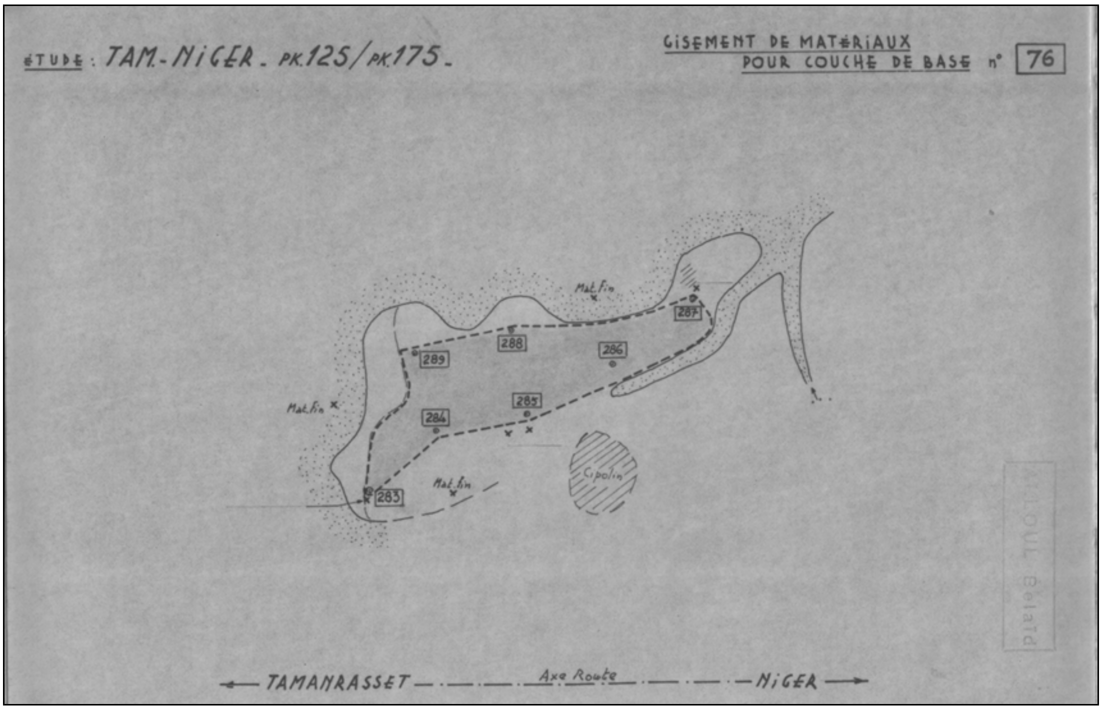


Figure 10 : Plan of a road materials quarry
on the Trans-Saharan (LNTPB Study: Mr Domec )

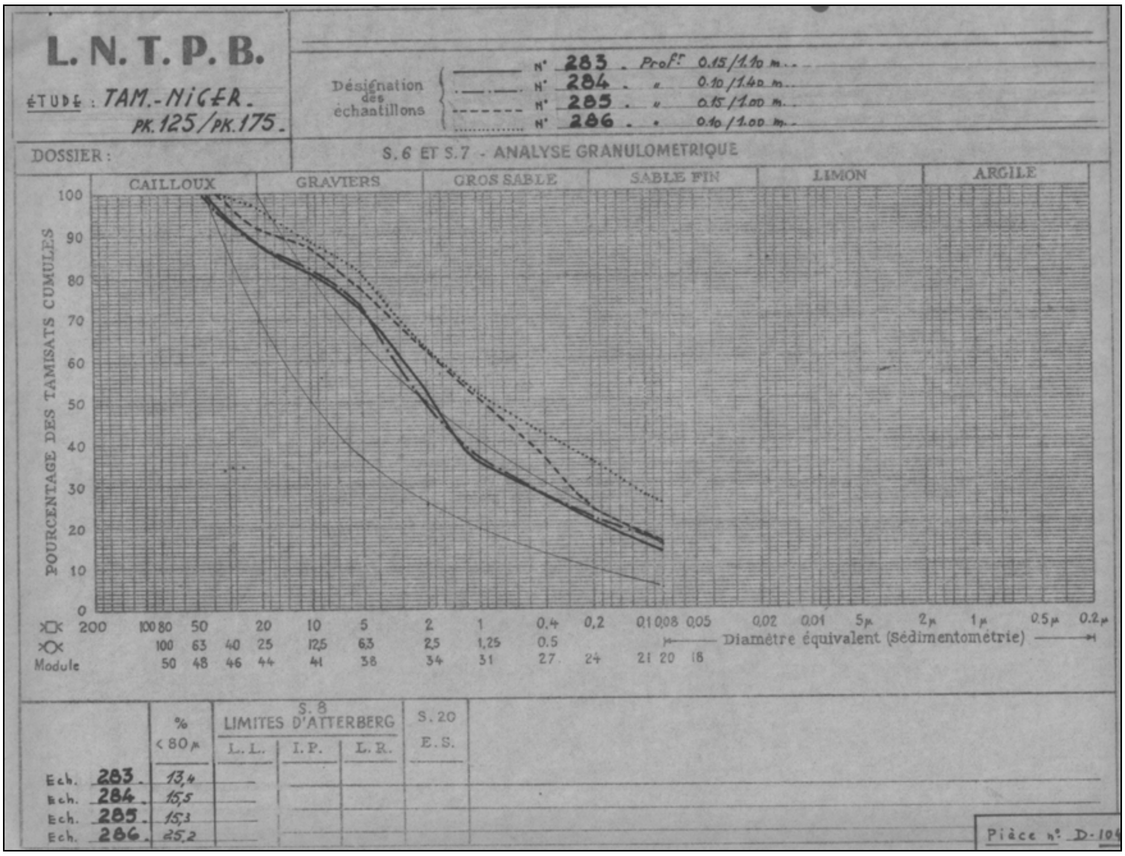


Figure 11 : Range of granitic arenas of the Hoggar and granulometry of
quarry materials (LNTPB Study: Mr Domec)

Figure 12 : Trans-Saharan route to Tamanrasset Airport
Base course of granitic arena

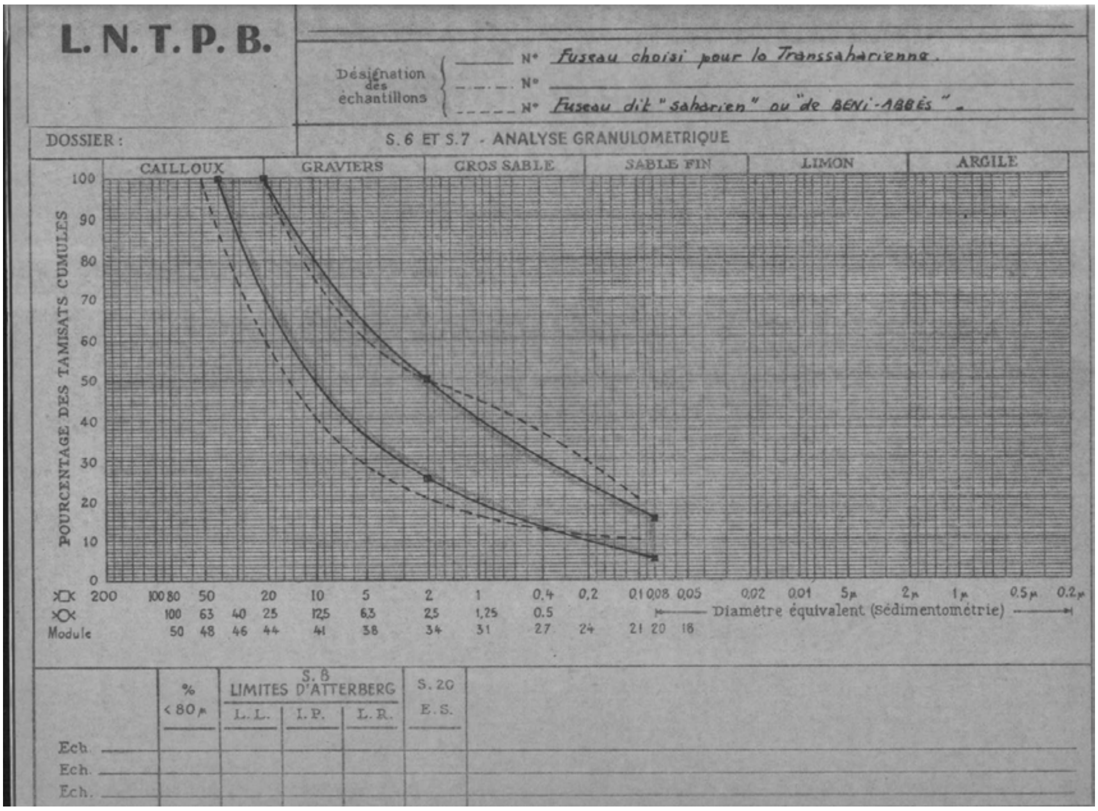


Figure 13 : Beni Abbes range and range adapted for the Trans-Saharan
(LNTPB: Mr Domec )

## 8. THE WHETHERED

When a basalt is weathered, it splits in characteristic scree, rough blocks that cover the 0/25 mm gravel deposits, gravel that is often well-graded of the crushed stone type ready to use. This type of deposit is quite uncommon along the projected roads due to the dispersion of the volcanic zones in the Hoggar. In contrast, the volcanic vents or chimneys and the scree deposits resulting from an explosive type eruption can be used as crushed material for wearing courses.

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## 9. THE CLAYS

Some very ancient clay series are very hard and are found in the form of rock. Example: the triasic series of Zarzaitine clays at *In Aménas*. These clays split in dozer extraction gravel and are used in road pavements on the Saut du Mouflon road at *In Aménas* in the base course and in the foundation course of the *In Aménas* airport. Humidified to a water content of 8% to 10%, well below the OPM, these materials were compacted using a light rubber tire roller. However, damage has appeared on these roads.

## 10. CONCLUSION

The use of untreated natural materials in road construction in the Sahara has produced good results with rare exceptions. Knowledge of the regional geology and the geomorphology as well as of local conditions of installation of the superficial formations require a study of the materials in the Sahara. Guided by now well-established specifications and by frequently itinerant field laboratory testing, the engineer can choose from a wide range of unconventional materials.

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