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*Full length article*

# PETROGRAPHIC INVESTIGATION OF LIMESTONE OF THE LAKI FORMATION USED IN CONSTRUCTION SECTOR FROM JAMSHORO AND THATTA DISTRICTS, SINDH, PAKISTAN

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## ABSTRACT

Limestone belonging to the Laki Formation is well exposed at Nooriabad, Jhampir, and Makli Hills. Representative samples of the Laki Formation limestone were collected from different locations such as Jamshoro, Bolhari, Makli Hills, and Nooriabad. The four crush plants i.e. Afridi Crush Plant and New Hazara Crush Plant (Makli, Thatta District), Shah Rahim Crush Plant and Bhatti Crush Plant (Nooriabad, Jamshoro District) were selected for sampling. The Petrographic investigation as per ASTM- C295-03 (1) was performed using standard thin sections. The megascopic and microscopic study results reflect no hindrance in using the studied limestone. For cement concrete, this limestone can be used for the low-strength concrete and aggregate base course and sub-base. Variation in lithology, stratification and non-homogeneity was observed, however, the aggregate from the New Hazara crush plant is found fractured in nature and therefore, its use as concrete material is not suggested. The studied limestone of all crushed plants does not show any potential for Alkali Silica Reaction (ASR) and Alkali Carbonate Reaction (ACR). Based on the present study, it is concluded that the studied limestone of the Laki Formation from the above-mentioned locations is suitable for construction purposes and industrial use. For cement concrete, this limestone can be used for the low strength concrete and pavement (sub-base & base coarse) as well as aggregate base course. In the stockpile of crushed aggregate on crusher plants, the chalky limestone was found to be less stable and less durable.

**KEYWORDS:** Construction, Concrete, Laki Formation, Limestone, Petrography, Pavement.

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## 1. INTRODUCTION

Several types of igneous, sedimentary and metamorphic rocks are used as construction and industrial materials in different ways. Amongst all these rocks the sedimentary rocks are of particular significance in the construction and industrial sectors [19, 21]. The sedimentary rocks are of several types having specific significance. Amongst various types, limestone has its significance and is more commonly used than other sedimentary rocks [2]. Besides other industrial uses; the major uses of the limestone are in the field of construction and cement industries [22]. In the construction sector, limestone is used for pavement of the structure, cement concrete, and asphalt concrete [23]. Apart from these major uses, some other important uses of limestone include hydrate lime, medicine, coal purification, animal feeding, and tile factories [18]. Before using the limestone for construction purposes, it is essential to check its quality. Several quality tests are required i.e., geotechnical, physical, mechanical and engineering tests. The most important

preliminary test is petrographic analysis [3]. Before the selection and approval of any source/quarry of limestone aggregate for concrete and asphalt, the petrographic examination must be performed as per the available standards i.e. American Society of Testing Materials ASTM C-295-03 [1]. The Petrographic examination is the main requirement of the client and is conducted according to client specifications and standards to check any potential alkali or silica reaction in the aggregate. Among these reactions; the most noteworthy are Alkali Carbonate Reaction (ACR) and Alkali Silica Reaction (ASR) which can cause cracking within concrete and eventually lead to material failure [4, 5]. During the Petrographic examination, the potential occurrence and degree of ASR/ACR ratio are also evaluated [6, 7, 8]. From the petrological standpoint, aggregate can be divided into several groups of rock having common characteristics, as classified by BS 812 parts 1, 1992 [9]. ASTM standard C-294-03 [10] describes more common or important minerals found in aggregate [11].

In Sindh, limestone deposits of the Laki range from the Laki Formation and Kirthar Formation have been used as construction and building stones for decades. The Laki Formation is very important as its limestone is used in different industries. The Laki Formation is divided into Chat and Sonhari members [12]. The Chat member is further divided into Meting Shale, Meting Limestone, Laki Limestone and Tiyon units that are well exposed throughout the Laki range and some part of the Kirthar range with major exposures around Nooriabad, Jhampir, Makli hills, Thana Bula Khan, Ranikot, Gaj Nala, and Bara Nala sections [12]. The Ypresian age is suggested of the Laki Formation based on smaller foraminifers' assemblage [13]. The reconnaissance survey revealed that all the present industries working on the limestone deposits do not use all deposits of the Laki Formation because of its diverse nature in terms of chemical composition, texture, petrography, strength etc. Therefore, the present study is conducted to address the above question. The sample locations are in district Jamshoro at Nooriabad and Bolhari and district Thatta at Makli (refer to Figs. 1 and 2). The geological maps of both studied areas along with sample sites; where commercial deposits of limestone are available and being exploited are mentioned in Figures 2 and 3.

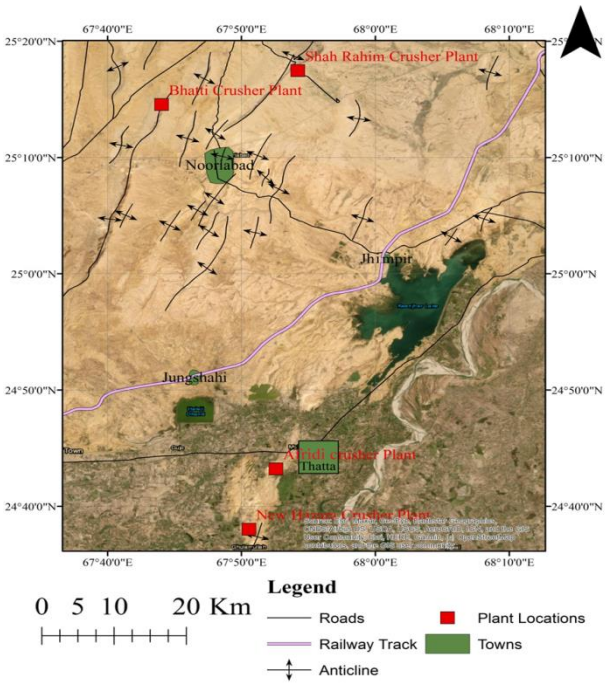


**Fig. 1.** Location Map of site areas showing sampling locations in Makli, District Thatta and Nooriabad, District Jamshoro.

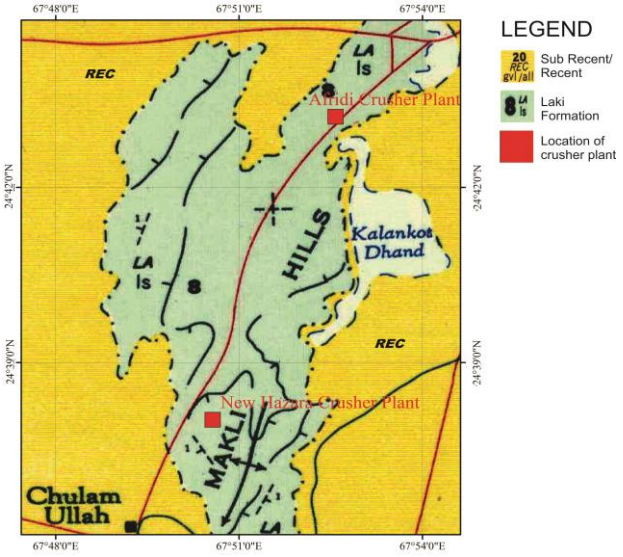


**Fig. 2.** Geological Map of Makli, Thatta showing study area along with coordinates.

## 2. MATERIALS AND METHODS

The crush plants in the study area are the very first sites where the usage of said limestone is determined in terms of construction or industrial purposes. Therefore, sampling was carried out from four crush plants located around the Nooriabad and Makli areas of Jamshoro and Thatta districts (Figs.1, 2 and 3) respectively. The sampled crush plants use different limestone units of the Laki Formation. The rock unit is mainly the same at different sites with significant macroscopic differences that are described in the petrography section.

Three representative samples of the Laki Formation limestone from each of the following crush plants were collected according to the prescribed specifications. A total of twelve [12] samples were collected from the following four crushed plants for petrographic investigation.

1. Afridi Crush Plant (Makli, Thatta)
2. New Hazara Crush Plant (Makli, Thatta)
3. Shah Raheem Crush Plant (Nooriabad, Jamshoro)
4. Bhatti Crush Plant (Nooriabad, Jamshoro)

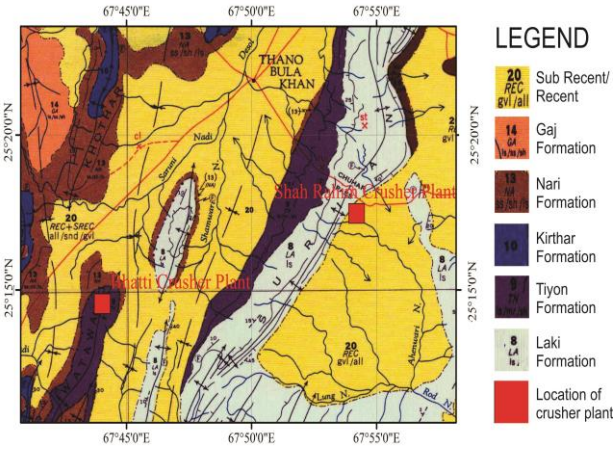


**Fig. 3.** Geological Map of Nooriabad, district Jamshoro showing study area along with coordinates.

Standard thin sections for petrographic studies were prepared. The selected samples were also washed and dried to check their macroscopic properties with a magnifying glass. Weathering effects and the presence of calcite veins or fractures, compactness and grain size were also observed. The collected crushed stone of limestone is of 39 mm to 10 mm size piece of aggregate. In petrographic tests, ASTM C-295-03 [1] method was followed. The petrographic analysis according to (ASTM C-586) [14] of concrete was carried out to investigate the nature of the defect(s) that take place in concrete. The Leica DM 2500 Advance Polarizing Microscope was used and is available in the Centre for Pure and Applied Geology, University of Sindh, Jamshoro. The petrographic investigation provides identification of rock types and their varieties present in aggregate and is also very important to know the Alkali Carbonate Reactive (ACR) and Alkali-Silica Reactive (ASR) potential of the aggregate. After the identification of rock type, the complete analysis of each sample was carried out and the results are described in the form of

microphotographs. In addition, the same selected samples are also analyzed for major element geochemistry. For this purpose, the WD-S4-PIONEER X-Ray Fluorescence Spectrometer is used which is available in the Centre for Pure and Applied Geology, University of Sindh, Jamshoro. For sample preparation, the method of Gakuto Takahashi [20] was used.

## 3. RESULTS AND DISCUSSION

Detailed results of the petrographic study of selected crush plants situated in the Jamshoro and Thatta districts are given below:

### 3.1 Afridi Crusher Plant

Afridi Crusher plant is situated along the Thatta-Ghullamullah road at around 5 kms distance from Makli City. Its location is 24°43'12.50"N and 67°52'3473"E. The samples are taken from the crush plant stockpile. The color of the fresh sample is reddish yellow, brown and cream color, with iron oxidation present; a few cavities are also present in aggregate. It is hard, compact and durable; fracture is conchoidal and is seen mostly in aggregate form (Fig. 4a, b). The sample is mainly composed of micrite or carbonate mud. The matrix consists of fine crystalline carbonate material having numerous micros to macrofossils (Fig. 4c, d). Fine-grained oxidation particles of iron are also observed during thin section study. Other than the iron oxide, no non-reactive and deleterious material in the carbonate pieces was observed.

Various species of foraminifera such as the assilina and nummulites (Fig. 5c, d) are observed in studied thin sections. The outer shell of these microfossils is carbonaceous. The thin sections display the absence of siliceous material. Hence, there will be no alkali-silica reaction and the aggregate stands safe in terms of ASR. A thorough inspection of thin-section indicates the carbonate mud as > 90% and the grains as < 10%. Therefore, the rock as per Dunham's (1962) classification is mudstone; and as per Folk's (1959) classification, the rock type is micrite [15, 16].

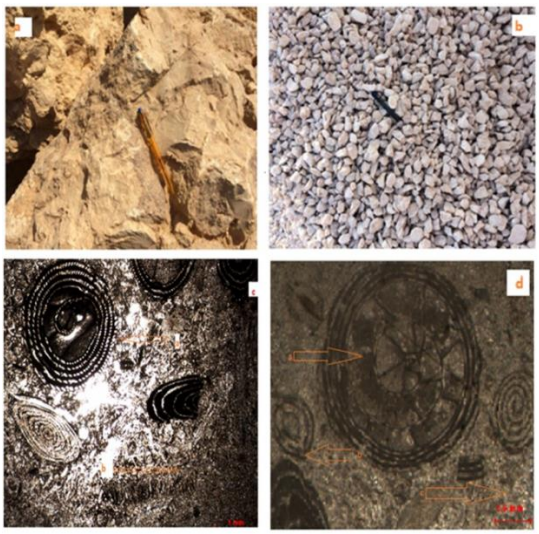

**Fig. 4. a)** Quarry of Afridi crusher plant **(b)** Aggregate of Afridi Crusher Plant Makli "Dist. Thatta". **(c)** Microphotographs of limestone from Afridi Crush plant. Crystalline calcite along with micrite. **(d)** The micro-fossils of different species of foraminifera are also present.

### 3.2 New Hazara Crusher Plant

The crusher plant named New Hazara is also located along the Thatta-Ghullamullah road at a distance of 03 kms to the south of the Afridi crusher. Its location is 24°38'01.04"N and 67°50'34.04"E. The outcrop represented three lithologically different types of limestone beds. The lower and upper beds are compact and hard; the middle part is comparatively soft and contains iron oxide in significant amounts. Therefore, the crush samples were taken from the upper and lower part (Fig. 5a, b). The thin section study indicates that the matrix is of fine carbonate crystalline material with numerous micro to macrofossils (Fig. 5c, d). Some bioclasts are seen within the micritic mud as well as in the sparry calcite. The

microfossils of Alveolina (foraminifera) are significantly present. The veins of calcite are also present along with sparry and granular calcite within the sample. No evidences of quartz or other type of siliceous minerals such as chert, opal, or chalcedony is observed. The limestone aggregate processed at the Hazara crush plant does not contain any reactive constituent or deleterious material. The sample mainly consists of sparry calcite, grains vary in size from 0.5mm to 1mm. As sparry calcite is the dominant cement, as per Folk's (1962) classification the rock type is bio sparite, while as per Dunham (1959) classification sample is grain stone [15, 16].

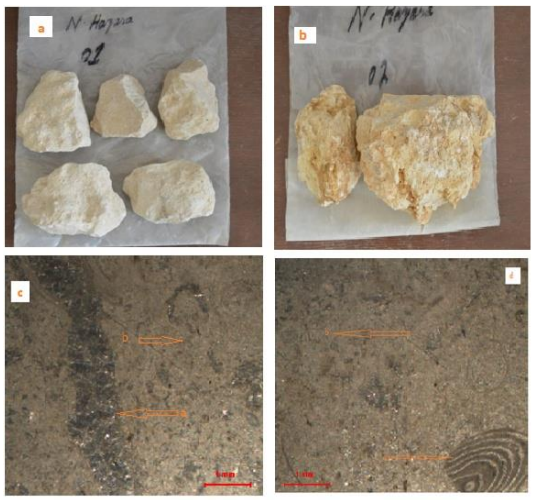

**Fig. 5. a)**and **b)** Aggregate of New Hazara Crusher Plant Makli "Dist. Thatta" **(c)** Microphotographs of aggregate sample from New Hazara Crush plant. Crystalline calcite along with micrite. **(d)** The micro-fossils of different species of foraminifera are shown on the right bottom side.

### 3.3 Shah Rahim Crusher Plant

The crush plant named Shah Rahim is near the Nooriabad industrial town on Hyderabad-Karachi, M-9 motorway. The crush plant is around 45 Kms away from Jamshoro Toll Plaza. Its location is 25°17'28"N and 67°84'12.3"E. The samples are collected from the aggregate stockpile. In hand specimens, the samples are white colored, relatively soft, less compact, medium-hard, and angular in shape, having small cavities of iron oxide (Fig. 6a, b). The oxidation is variable with spot sizes from 25 mm to 50 mm at places. The fractures are conchoidal and appear just like chert. The fossils seen are mainly alveolina (foraminifera).

The thin section observations of the aggregate samples from this crushing plant reveal the sample mainly comprises carbonate mud (upto 95%) with other constituents including fossils (up to 5%) as evident in Figure 6. Minor cracks in thin section of the sample indicate weak zones suggesting the limestone unfit for use in cement concrete. There are no showings of the quartz, any other type of silica, or alkali hence the aggregate has no potential evidence of alkali silica reaction (ASR). The carbonate mud and other constituents' proportion in the studied sample declare it mudstone as per Dunham's (1962) classification and as per Folk's (1959) scheme for carbonate rocks, the aggregate is micrite [15, 16].


**Fig. 6. (a , b)** aggregate photographs of Bhatti Crush plant, Nooriabad **(c,)** Microphotograph where carbonate mud is a dominant phase, spotty iron oxide is also present, **(d)** foraminifera and bivalves present.

**Table 1.** Major element geochemical XRF analysis of different limestone samples of Afridi (AFC), New Hazara (NHC), Shah Rahim (SRC) and Bhatti (BTC) Crush Plants.

| Sample No. | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $Na_2O$ | $K_2O$ | Cl | LOI | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **AFC-01** | 1.20 | 0.03 | 0.15 | 55.90 | 0.40 | 0.01 | 0.17 | 0.04 | 0.05 | 42.05 | **100.00** |
| **AFC-02** | 1.18 | 0.05 | 0.20 | 55.80 | 0.45 | 0.01 | 0.18 | 0.05 | 0.03 | 42.05 | **100.00** |
| **AFC-03** | 1.22 | 0.04 | 0.17 | 55.40 | 0.44 | 0.01 | 0.15 | 0.06 | 0.03 | 41.48 | **100.00** |
| **NHC-01** | 1.28 | 0.03 | 0.00 | 55.99 | 0.50 | 0.01 | 0.15 | 0.03 | 0.01 | 42.00 | **100.00** |
| **NHC-02** | 1.25 | 0.05 | 0.00 | 56.27 | 0.48 | 0.01 | 0.17 | 0.04 | 0.02 | 41.70 | **100.00** |
| **NHC-03** | 1.14 | 0.02 | 0.00 | 56.25 | 0.43 | 0.01 | 0.15 | 0.02 | 0.02 | 41.96 | **100.00** |
| **SRC-01** | 2.27 | 0.07 | 0.06 | 55.02 | 0.34 | 0.01 | 0.16 | 0.04 | 0.03 | 42.00 | **100.00** |
| **SRC-02** | 2.24 | 0.05 | 0.04 | 55.25 | 0.36 | 0.01 | 0.17 | 0.05 | 0.02 | 41.81 | **100.00** |
| **SRC-03** | 2.28 | 0.08 | 0.05 | 55.05 | 0.33 | 0.02 | 0.19 | 0.03 | 0.03 | 41.94 | **100.00** |
| **BTC-01** | 1.55 | 0.17 | 0.18 | 55.08 | 0.78 | 0.01 | 0.16 | 0.05 | 0.03 | 41.99 | **100.00** |
| **BTC-02** | 1.53 | 0.21 | 0.19 | 55.18 | 0.74 | 0.01 | 0.15 | 0.03 | 0.04 | 41.92 | **100.00** |
| **BTC-03** | 1.51 | 0.11 | 0.22 | 55.50 | 0.72 | 0.01 | 0.16 | 0.03 | 0.02 | 41.72 | **100.00** |

Based on present results, the effects (presence or absence of potentially harmful constituents in aggregate based on present results, the effects (presence or absence of potentially harmful constituents in aggregate) especially on the industrial and construction uses, studied aggregate materials are described below.

The samples of aggregate from the Afridi Crush Plant are found to be compact, hard, and massive. The samples due to their physical properties are suitable for high-strength concrete (4000 psi) and asphalt concrete work. The megascopic and microscopic examinations reveal no hazard but before approval for construction use, the mechanical engineering properties be checked. As per ASTM C-150 [17] for finished cement products this limestone is highly recommended.

The crushed aggregate from New Hazara Crush Plant contains a very small proportion of $SiO_2$ as is mentioned in Table1.The $SiO_2$ could be any type of silica such as quartz, chalcedony, opal etc. The presence of other alkalis is also low (Table 1), hence, it is considered non-deleterious with no chance of Alkali Carbonate Reaction (ACR) and Alkali-Silica Reaction (ASR) potential. The samples of crushed aggregates are of two varieties. One marks the presence of quartz in a minor proportion which could be hydrophilic. However, the other belongs to the hydrophobic aggregate. A few calcite veins are also observed (Fig. 5) in the aggregate samples. Therefore, the physical and mechanical engineering properties are strongly recommended for use as asphalt concrete and high-strength concrete. It may be used as low-strength concrete (A-1, A-2 and B) class concrete as well as an aggregate base coarse.

The samples of crush aggregate from Shah Rahim Crush Plant contain very small traces of quartz (2.24 to 2.28 %) as is evident from the chemical composition (Table1), which suggests the crush aggregate is

hydrophilic. The other part of crush sample represents hydrophobic aggregate. Within aggregate some cracks are also observed (Fig. 5); hence based on visual observation (softness and minor cracks), the aggregate cannot be recommended to be used as asphalt concrete and high-strength concrete work. However, the physical, mechanical and engineering tests are strongly recommended. Stratigraphically, within the quarry area of this sample the lithological difference is observed as compared to other limestone quarry sites. This limestone is suitable for concrete i.e., class A-1, A-2, lean concrete, and the base coarse, granular sub-base, after performing all the required tests as per given standard and specification.The aggregate from Bhatti crush plant is massive, stable, and hard. According to the chemical composition results (Table 1), the crushed aggregate contains a small proportion of $SiO_2$ which could be quartz or any other form of silica. Along with silica, a very small concentration of alkalis is also seen in the chemical composition of analyzed samples. Therefore, the aggregate is characterized as non-deleterious and has no chance of Alkali Carbonate Reaction (ACR) and Alkali Silica Reaction (ASR) potential. The aggregate of Bhatti crusher samples after performing all the required tests as per specification NHA 1998 [3], if it is within limits may be recommended for asphalt concrete and high-strength concrete work.

## CONCLUSION

Based on the Petrographic finding of limestone samples from different crush plants; the following conclusions are drawn:

- In the studied samples the presence of reactive and harmful minerals was not observed during the petrographic examination except in the samples from Shah Rahim crush plant which were weak, fractured, soft and less compact than other limestone aggregates.
- The samples from studied crush plants did not suppose any potential of ACR and ASR.
- The aggregate samples from the Bhatti crush plant, Nooriabad, Dist. Jamshoro and Afridi crush plant Makli, Dist. Thatta is suitable for asphalt concrete and cement concrete.
- From the perspective of construction uses, all crush plant's aggregate are not suitable due to their variation in lithology, and non-homogeneity which affects the quality of cement concrete and asphalt concrete. However, the petrographic analysis is the primary test for the selection of aggregate for use in construction; so far, other engineering, mechanical and physical tests are required to be conducted according to given specifications and standard codes for final approval of aggregate material.

## DECLARATION

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**Data availability:** Not applicable/as the case may be.

**Code availability:** Not applicable.

**Authors' contributions:**

FATEH A. BALOCH: Conceptualization, Methodology, Investigation, Writing-Original draft preparation

MUHAMMAD HASSAN AGHEEM: Conceptualization, Supervision, Manuscript Reviewing and Editing

*AKHTAR HUSSAIN MARKHAND*: Manuscript Reviewing and Editing.

*KASHIF AHMED MEMON:* Manuscript preparation

*RAFIQ AHMED LASHARI*: Manuscript preparation

GHULAM MUSTAFA THEBO: Manuscript preparation

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