Proposed Material Modification through the use of Polymer and Nano-technology to render marginal coarse aggregate fit for use in higher order, and upper Pavement layers

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***Abstract*— In order to lower the impact of road construction activities through preserving scarce road construction material sources for the future, thinner and potentially stronger, less water-susceptible to failure pavement layers must become the norm. Compaction water must be utilized wisely, and not absorbed into the slightly weathered marginal aggregates, without any meaningful construction benefits.**

The use of lower quality in-situ construction material and water haulage quantities, are not always considered during the design of site specific and appropriate road pavements.

The arid Karoo and Kalahari Regions are known for a lower groundwater potential and quality resulting in expensive road construction boreholes, with yields that could be very low. In general, the Beaufort and Ecca Groups in these areas yield poor ground water quality with a very high saline content.

The R75, which is a low volume route from Jansenville to Graaff Reinet, is such a project in these areas. Other strategies will be required to use unconventional water sources and/or water saving construction technologies to ensure the feasible construction of this road. Material modification and water-wise construction as well as pre-treatment of marginal coarse aggregate and/or high saline groundwater must be considered.

Therefore, construction methodologies, approaches and design philosophies which require better understanding of the sub-grade support, using of materials of lower quality, less compaction effort, which have to be further pursued, especially in an environmental and regional climate change context.

Keywords—Marginal Aggregate; Construction Water Scarecity; Problematic mineralogy; Materials Modification; Remote Sensing;

I. Introduction

Material haulage of suitable and appropriate road construction materials is one of the key parameters determining the final construction costs of a road, as well as pavement performance. The scarcity of suitable road construction materials in parts of Southern Africa requires that certain principals of scientific mineral exploration must be employed to demarcate the most appropriate material resources along a given road alignment. A geological and geophysical understanding of the route also enhances structural and engineering geological parameters which may influence the final cost and life expectancy of the pavement. Key zones which may require further detailed geotechnical scrutiny could be identified at this early stage.

A more scientific approach making use of all the available datasets from space borne, airborne geophysics, as well as detailed site specific fieldwork will ensure better and more cost effective pavement designs by making use of the most appropriate road building materials.

The pavement and geotechnical behaviour of many natural occurring geological materials are severely compromised by the presence of higher than acceptable levels of deleterious minerals, which is mostly concentrated in the weathering products of the primary rock-forming minerals, also known as secondary minerals (clay mineral families).

Amorphous silica and even quartz, if the latter is intensely fractured will severely compromise the durability of the construction material. It is even more apparent if more than 30% of the quartz crystals in rocks such as granite, gneiss or sandstone are strained and is prone to the adverse reactive silica reaction.

Primary rock-forming minerals are always in a state of potential change to secondary minerals, depending on the environmental, physical and chemical parameters and attributes in a specific closed and/or open system. This is also applicable to the group of feldspathoid minerals, present in certain basic magmas which contain excessive potassium, sodium and aluminum in relation to available silica.

In order to make roadbuilding affordable and to lessen the environmental impact, smaller areas of material extraction must be used, closer to the point of demand. In many instances, such as the Karoo Supergroup, the geology was historically subjected to generally uniform tectonic, geomorphologic and sedimentation processes over relatively large sections of the wider depositional basin. These sedimentary rocks are in many instances not “ideal” construction materials, which if untreated, generally show a high affinity for water. The sediments easily deform due to high plasticity and low shear resistance when wet under traffic loading.

Many modern organic and inorganic “nano-sized” derivatives are now available from various industrial processes in the form of full or half-processed “resins” and can be called in layman terms, potential glue-agents from the pulp, sugar and biomass-sectors. Nano-derivatives are more and more the focus of in depth research. The main objective is to evaluate the potential chemical modification of abundant and/or selected “problem minerals” on a microscopic scale, in stable formulations. The targeted undesirable minerals in lower grade and marginal material, may improve the geotechnical properties and make them suitable for higher use in the road prism, or avoid the spoiling of vast quantities of spoil material.

After the appropriate nano-treatment, the geotechnical properties of the natural parent material may be improved. Road-building (Pavement) Engineers, must take note of the requirement for this crucial interaction between Science and Engineering and must steer away from a “One Fix All” approach

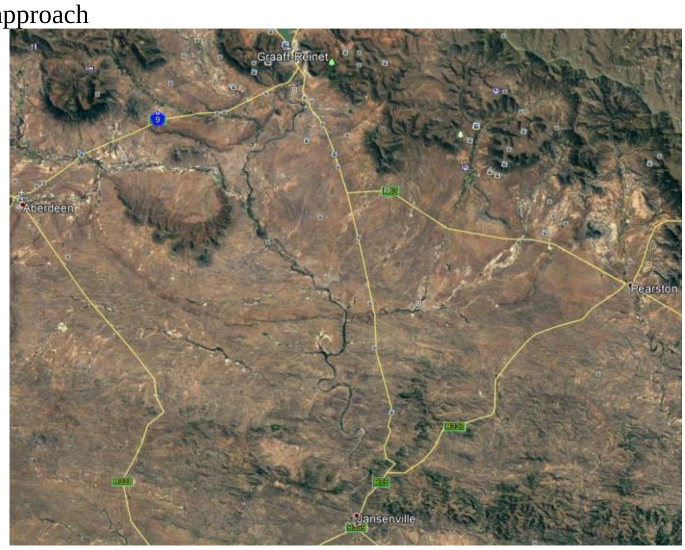

Fig. 1 Google image showing the R75 between Jansenville and Graaff Reinet.

II. GEOLOGY

The Karoo Supergroup is the most widespread stratigraphic unit in Africa south of the Kalahari Desert. The supergroup consists of a sequence of units, mostly of non-marine origin, deposited between the Late Carboniferous and Early Jurassic, over a period of about 120 million years [1].

In southern Africa, rocks of the Karoo Supergroup cover almost two thirds of the present land surface, including all of Lesotho, almost the whole of Free State, and large parts of the Eastern Cape, Northern Cape, Mpumalanga and KwaZulu-Natal Provinces of South Africa. Karoo supergroup outcrops are also found in Namibia, Swaziland, Zambia, Zimbabwe and Malawi, as well as on other continents that were part of Gondwana. The basins in which it was deposited formed during the formation and breakup of Pangea [2], [3]. The typical area of the Karoo Supergroup is in the Great Karoo in South Africa, where the most extensive outcrops of the sequence are exposed [3], [4]. Its strata which consist mostly of shales and sandstones [5], record an almost continuous sequence of marine glacial to terrestrial deposition from the Late Carboniferous to the Early Jurassic. These accumulated in a retroarc foreland basin called the "main Karoo" Basin (Fig.2) [4]. This basin was formed by the subduction and orogenesis along the southern border of what eventually became Southern Africa, in southern Gondwana [4]. Its sediments attain a maximum cumulative thickness of 12 km, with the overlying basaltic lavas (the Drakensberg Group) at least 1.4 km thick [6].

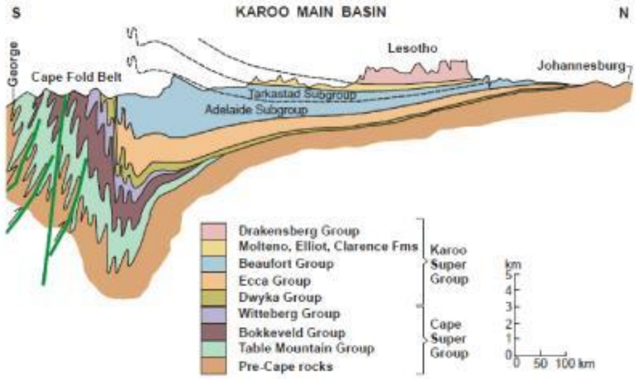

Fig. 2 Geological cross-section of Karoo Lithology of the Karroo Basin [7].

About 510 million years ago a rift valley developed across Southern Gondwana, just south of Southern Africa. An 8 km thick layer of sediment, known as the Cape Supergroup, accumulated on the floor of this rift valley. Closure of the rift valley, starting 330 million years ago, resulted from the development of a subduction zone along the southern margin of Gondwana, and the consequent drift of the Falkland Plateau back towards Africa, during the Carboniferous and early Permian periods.

After closure of the rift valley, and compression of the Cape Supergroup into a series of parallel folds, running mainly east-west, the continued subduction of the palaeo-Pacific Plate beneath the Falkland Plateau and the resulting collision of the latter with Southern Africa, raised a mountain range of immense proportions to the south of the former rift valley. The folded Cape Supergroup formed the northern foothills of this mountain range.

The weight of the Falkland-Cape Supergroup Mountains caused the continental crust of Southern Africa to sag, forming a retroarc foreland system, which became flooded to form the Karoo Sea. Sedimentation, began with glacial deposits from the north, but later from the Falkland Mountains to the south, into this depression formed the Karoo Supergroup.

Between Jansenville and Graaff Reinet, the rocks of the Karoo Supergroup consist of the Dwyka and Ecca Groups. It consist mainly of tillite (diamictite), shale, sandstone and intrusive dolerite from the break-up of Gondwanaland.

However, the role of intrusive geology (Dolerite-heat), tectonics (Mineral strain/stress), as well as maximum burial depth (Regional metamorphism and induration) are not fully appreciated and/or quantified in material- and road engineering. Durability testing seldom address the entire suite of potential "reactive minerals" and the less obvious ones are totally ignored, or missing in the material sample taken and "problematic, material / petrographic assemblages", stay unknown in many instances. However, any linear infrastructure development (roads etc.) with medium to large sections will therefore trespass, homogeneous / or heterogeneous mineralogical and metamorphic settings, which mitigate strongly against or in favour of stable/unstable petrography (rock-assemblages). These material related problems only crop-up during detail testing and quality control in the construction phase.

As quartz is the most abundant mineral, the preventative treatment of potential reactive silica with appropriate nanotechnology, seem a worthwhile approach to reduce the risk of any unstable atoms in any chemical formulation. Maximum stability and highest chemical inertness are the most valuable characteristic of the mineral, quartz. Therefore, the modification of potential "unstable minerals, especially in quartz and clay families" are the overall objective for long term durability and better performance, of marginal materials.

Quartz, the feldspars, the micas, amphibole, pyroxenes and olivines are the minerals which characterize crystalline rocks. Quartz can be in a stable tetrahedron form or may occur as high-temperature modifications such as trydymite and cristoballite. They may have been formed in igneous rocks during the early stages of cooling, and now form the subordinate component in the rock's mineral assemblage.

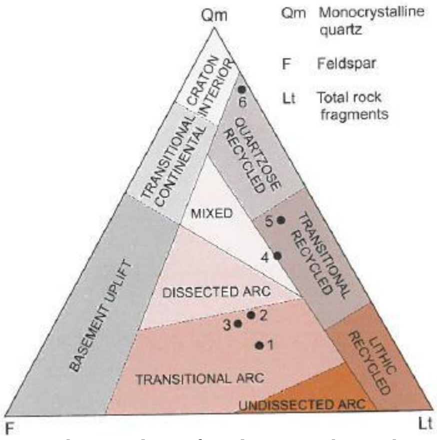

Fig.3 Framework mineralogy of sandstones in the southeastern part of the main Karoo Basin [7].

None of the modifications of silica, is in proper equilibrium with the surface conditions and over geologically times they are apt to change into quartz. In this and any other process of rearrangement of the atoms in the silica containing crystal, a stage occurs when part of the silica is in an amorphous state. In contrast to the high chemical inertness of silica crystallized as quartz, amorphous silica is chemically very reactive.

The sodium member of the group takes the place of the sodium plagioclase albilte. Chemically, these are feldspars and feldspathoids, but with added water and are the members of the mineral group zeolites. Among the latter the cubic member analcime, also called analcite and is related to nepheline (Fig 3).

This are in many instances not fully appreciated, and will fundamentally change the geotechnical and engineering characteristics and behaviour of an any completely fresh parent rock, and if some zeolite minerals comes into play even greater substantial changes occur. Sub-microscopic nepheline and/or volcanic glass, when exposed to heat are subjected to mineralogical change and massive volume changes, with detrimental effects on any aggregate containing even lower to trace amounts of these problematic constituents.

III. OBJECTIVES

The main objective on the R75 project is to identify and use materials generally not considered acceptable for use in the upper road layers for this lower volume link between Port Elizabeth and inland. Commercial, premium quality materials are only available at considerable distance, thus allowing marginal materials to be considered for utilization. However, methods need to be found to modify or stabilize these materials to ensure durability and decreased water susceptibility, and long-term performance. Nano-technology opens potentially new opportunities for the use of these marginal materials.

The need for the identification of fractures, dykes and faults with poor sub-grade support, which require special attention, needs to be identified with appropriate scientific methodologies such as airborne and ground-based geophysics, to distinguish and delineate uniform sections.

IV. METHODOLOGY

The major steps for finding building materials for road construction are applied in the following sequence:

- The first step is to evaluate the area using remote sensing techniques. This include satellite data (Landsat) (Fig 4) as well as airborne magnetics (Fig 5) and radiometrics [8].
- The second step is to investigate the possible areas indicated by the remote sensing techniques by visiting the areas. If material is confirmed, samples are taken for laboratory analysis and the possible material resource is estimated by ground geophysical surveys and ground truthing (drilling).
- All problematic structure and fracturing are also identified along the route.
- Samples are taken for chemical analysis (mineralogy) to determine the most efficient nano agent and the relevant dosage.
- Based on this the most appropriate material is selected and the design is carried out.
- The next step is the construction of test sections of at least 500 m and are regularly evaluated and inspected.

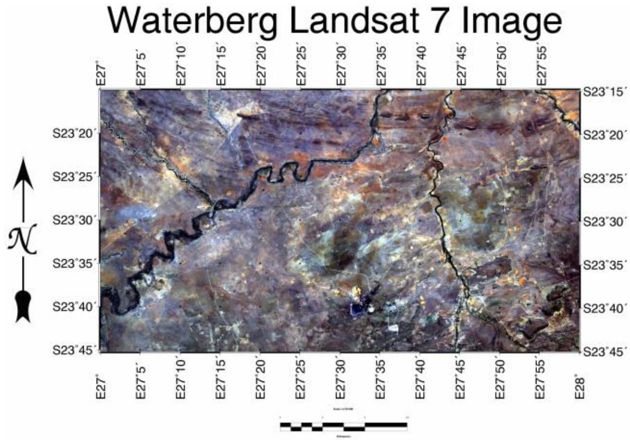

Fig.3 Example of a Landsat 7 image.

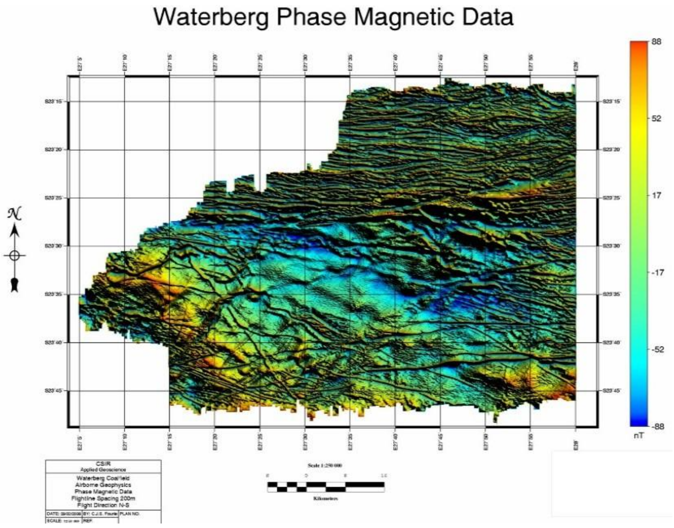

Fig.4 Example of an Airborne Magnetic image.

V. CONCLUSIONS

Premium construction materials is becoming less readily available. Geology of the Karoo Supergroup is the most widespread in South Africa, but generally contains some of the most deleterious constituent materials (clays and reactive silica) that tends to be problematic for cementitious stabilization. Nano technology is therefore a viable option to address some of these issues

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