SOME PRACTICAL ASPECTS REGARDING THE HANDLING OF DOLERITE FOR BASE AND SUB-BASE CONSTRUCTION

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ABSTRACT

Good quality base and sub-base material for road pavement construction is becoming increasingly scarce. Dolerite is one of the more abundant natural road building materials in South Africa. Yet, it seems that the road design and construction fraternity shy away from using it in favour of more expensive commercially produced crushed material – and so artificially increase the scarcity of natural base and sub-base material. Could this actually be because the knowledge and know-how of handling dolerite is being lost?

This paper intends to assist in reversing this dwindling spiral by exposing some of the myths regarding the application of dolerite material for base and sub-base pavement layers. The nature and background of dolerite as a road building material is discussed as well as the traditional road building cautions as they relate to the latest understanding of the material – based on the experience of the authors, supported by the findings of a CSIR research programme that they are involved in.

1. INTRODUCTION

Good quality base and sub-base material for road pavement construction is becoming increasingly scarce. Dolerite is one of the more abundant natural road building materials in South Africa. Yet, it seems that engineers, technicians and contractors in recent years tend to shy away from using it in favour of more expensive commercially produced crushed material, and so artificially increase the scarcity of natural base and sub-base material. Could this be because of the myths surrounding the use of dolerite, and/or that the knowledge and know-how of handling dolerite is being lost?

This paper aims to assist in reversing the dwindling knowledge spiral by discussing some basic characteristics of dolerite and giving practical advice regarding the selection, testing, treatment and application of dolerite for base and sub-base course construction, especially in relatively water surplus areas (Weinert $N < 3$).

Strictly speaking, the effective application of dolerite-to-road construction starts by knowing what one is looking for and whether it may be found in the area, in what form and how best to win it (with due respect for environmental legislation). However, these “prospecting” aspects do not form part of this presentation. The nature and background of dolerite as a road building material will be discussed as well as the traditional road building cautions related to the latest understanding of the material.

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2. DOLERITE

Dolerite is a basic crystalline igneous rock that essentially contains no free quartz and occurs over an enormous area of the country in the form of sheets, dykes and intrusions. The degree and nature of geological time scale weathering of dolerite is intimately associated with the climate and its geographical and depth location over time. The weathered form can usually be identified fairly easily in the field by its orange to brown colour (see Figures 1 and 2 for examples).

The progress made over the years in handling and understanding dolerite is, for the most part, based upon the application of traditional soil tests, coupled with keen observation in practice, to which some practical thinking was applied to develop the presently available guidelines and assessment procedures/indicator tests. To better explain and prepare the user for the peculiarities inherent to dolerite materials, various assessment methods and tests were developed (Paige-Green, 2007 and 2008) to augment the ability of the existing road building soils tests to predict durability/ performance, some more successful than others.

However, often one sees the newly developed (and more expensive) design and construction philosophies and aids being applied without regard for the “basics” behind the development. For instance, the latest equipment and soil stabilisation techniques may be applied but with disregard for workable maximum aggregate size in layer work, resulting in “inexplicable” poor layer integrity and riding quality, or the initial lime consumption tests are done but not heeded when the stabilizer dosage rate is considered. And since the successful application of a material depends on the interpretation of the test results (indicators) and precautions, with understanding of the reasoning behind it, handling dolerite effectively tended to become a bit of an “art” and myths started to develop around it.

3. DOLERITE MYTHS: DISCUSSION AND HANDLING

3.1 Myth 1: “High quality dolerite is too hard/difficult to process”

One must appreciate the fact that dolerite deposits weather inwards – from the top down and from the sides inwards. In other words, the more weathered and softer material will be closer to the surface or sides of the dyke (refer to Figure 1a). This tells one that the material must be prospected/selected with the application in mind. Gravel for pavement layers will be found within the first horizon and can normally be winned by ripping and dozing in a borrow-pit setup, however, under specific circumstances, the weathered dolerite mass need to be loosened by judicious use of explosives.

Material for surfacing or Crushed Stone base (G1 & G2) aggregate will normally only be found in the third horizon, which, although jointed, is normally very hard and non rip-able. This implies that a proper quarry and well-controlled crushing plant will have to be established, especially because of the hardness of dolerite and its propensity for producing insufficient fines – tempting one to correct the grading with lower quality weathered fines.

However, even the gravel within the first horizon can contain hard shards or cobbles (refer to Figure 2d) which, if not broken down or removed, can cause the following unwanted situations:

- Inefficient mixing of material in general – especially when containing clayey lenses or clods that need to be evenly distributed throughout the mix.
- Inefficient distribution of modifier/stabilizer due to difficult/poor mixing.
- Drag marks on the surface of the layer that will negatively affect the final finish (and performance) of the layer.

- Low densities/bearing capacities around oversized stone at the surface of the layer.

Sometimes such pieces within the gravel material cannot easily be broken down even by aggressive grid rolling. The cost of energy has escalated substantially and the breaking down by trains of grid rollers of very coarse material has largely become uneconomical. On the other hand, the advantages of electing to first crush the scalped/ripped weathered material, using a primary crusher, are quite significant – especially considering the energy and time that will be saved on the road thereafter. This also has the added advantage of limiting the footprint of the source. (One could remove the remaining oversized material by hand but it will only be cost-effective if the gravel contains few oversize pieces and labour is abundant, relatively inexpensive and conscientious.)

It is, therefore, recommended that very coarse or cobble-weathered dolerite gravel be crushed along with the finer components of the mixture, using a (mobile) primary crusher. The advantages are the following:

- The grading of the gravel is improved, making it easier to compact and achieve the desired bearing capacity.
- The gravel is more workable, and final levels and finish are readily achieved.
- Relatively small percentages of modifying/stabilizing agent (if specified) can be efficiently added during the crushing process when stockpiling the material.
- Any pieces of suspect material can be crushed and evenly distributed in the stockpile, e.g. lessening the danger of clay clods being built into the layer.
- Generally the material required for base or sub-base layers is significantly more uniform and quality control of the material is enhanced.
- Large volumes of dolerite material (with a limited source footprint) become accessible for base quality construction, resulting in major savings in haulage costs.

3.2 Myth 2: "More workable dolerite is usually too fine-grained/marginal"

Relatively fine grained dolerite gravel (Figures 1b and 2a) is normally well weathered and not difficult to win from a borrow-pit. However, the strength and other qualities of the material may be "marginal" for the intended application and it may contain lenses or clods of more weathered or clayey material. Obviously, if possible, such areas should be avoided in the borrow-pit in favour of adjacent uncontaminated material and/or the material can be mechanically improved by mixing with better/coarser material. If this is not practical, the following may be done:

- Remove the clay lumps by manual labour once the material has been spread out.
- Mix the clayey material/lumps thoroughly into the rest of the material by mechanical means if the contamination is relatively low. This implies that the appropriate soil tests should be applied to a representative sample of the material with and without the obviously clayey component and a decision taken on the basis of this outcome.
- Treat the mixed material with lime and re-test/evaluate its applicability to the specific situation – it will dramatically lower the PI and improve the bearing capacity (refer to paragraph 3.5).
- This is a case where the lime can be added, watered, mixed and left to cure for 24 to 48 hours before mixing again prior to compaction. (Consideration could be given to applying the lime in two equal phases depending on the amount of lime required.)

Keep in mind that the specifications are aimed at providing guidelines towards generally acceptable performance/durability and may not necessarily strictly apply to the situation and area at hand. The grading modulus (GM) is one of the parameters that could be relaxed for lighter pavements, provided the other parameters such as CBR/UCS, PI, etc. are acceptable. From experience, a base course GM as low as 1.0 for low to medium bearing capacity roads can still be acceptable.

There is no reason not to use “marginal” material, as long as one knows in what respect it is marginal and what to expect and do about it. However, all material to be considered or used should be standardly tested and evaluated appropriate to the intended application in a soils laboratory, especially basic crystalline material such as dolerite. The following is recommended:

- Apart from doing the normal tests (grading, CBR, PI, etc.), also find out what its PI-to-lime ratio need/initial lime consumption (ICL) is – refer to paragraph 3.3.
- Assess the quality variability of the borrow-pit and the consequences with respect to the project – never work a borrow-pit outside of the test-approved boundaries.
- Apply appropriate and effective borrow-pit and road material quality control.
- Exfoliate layered dolerite pieces/cobbles on the road by grid rolling prior to/during addition of the stabilizing agent – mobile crusher recommended if a concern.
- Ensure that the contractor/site personnel understand the implications, know what to do and actually do it.

3.3 Myth 3: “Weathered dolerite rapidly deteriorates to unacceptable levels”

Claims have been made that stockpiled dolerite, and even dolerite within a pavement, can weather and deteriorate dramatically over a short period. Cases are bandied about where very acceptable stockpiled or even layered dolerite material totally failed re-evaluation after a year – “the PI returned” and “the CBR was lost”. The authors also have experience of claims that dolerite within a pavement had decomposed to “pure clay” over a mere number of years, while investigation showed that the specified material was never imported but the inferior in-situ material was used to “save time”. This phenomenon of so called “rapid weathering” was recently extensively investigated by the CSIR (Kleyn et al, 2008).

Normally, in nature, the decomposition of dolerite occurs on a geological time scale over many millennia. These rocks have been subjected to alteration during their cooling and crystallisation. This caused some of the primary minerals in the rock to partially change to active clays that are not associated with significant discolouration and are thus part of a seemingly unweathered material. X-ray diffraction analyses on dolerites will show this to be the case. Of these clays the smectite group is of primary interest since they are the more active and thus destructive when exposed. While more plentiful in dolerite, the more weathered the material is, it is still present in relatively unweathered “fresh” dolerite – only it is still locked into the rock matrix.

From the work that has been done to date on this project it is quite clear that the finer the “fresh”/”hard” rock is (ground down) the higher the PI tends to register (the more clay minerals are released) – e.g. when doing the mixing of the 0.425 mm material the longer the mixing continues the more the measured PI tends to increase. If the minus 0.075 mm fraction of the minus 0.425 mm material (on which the standard PI test is done) is increased, the PI of the overall material sample will increase - the mineralogical clay content does not increase in such a short-term activity.

The question, however, is how does the mechanical break down of the "hard" dolerite which takes place "instantaneously" time wise, and releases the clay minerals contained in the rock/aggregate, equate to the time taken to release the clay minerals in the weathered "soft" dolerite. There is obviously no practical relationship of consequence between "instant time" and "millennia", the geological time taken for dolerite to be affected by the atmosphere or weather.

What has been established is the following:

- The amount of clay minerals can readily and economically be determined by X-Ray Diffraction analysis.
- There is a definite relationship between the percentage clay minerals and the PI of weathered "soft" dolerite material.
- The mineralogical clay content of dolerite does not, for practical purposes, increase during short-term physical breakdown of the material.
- The difficulties related to the clay content and, hence, performance of "Hard", "Intermediate" and "Soft" dolerites can be successfully and economically handled with lime treatment (refer to paragraph 3.5).

This relatively new understanding better explains a number of observed phenomena, which might have led to the origin of some of the myths.

3.4 Myth 4: "Crushed fresh dolerite deteriorates rapidly in the road"

It has been observed that Crushed Stone base (G1 & G2) made from apparently sound "fresh" dolerite can seemingly "deteriorate" to a state where the PI is in excess of the specified maximum and loose interlock friction, and fail upon wetting up and/or freezing cycles. This is basically the same mechanism at work as described in paragraph 3.3 above. Once the dolerite has been broken down mechanically during construction and/or traffic loading, the smectite contained within is more readily exposed.

When rolling and slushing a Crushed Stone base (or even G3 & G4 material) a certain limited amount of grinding down of the material occurs and the fines (essentially minus 0.075 mm material) is worked to the surface of the layer. If a standard PI test is then carried out on the top say 25 mm of the layer, the PI will be found to be significantly higher than the PI done on the material from the total depth of the layer. Hence, the PI which initially was less than 4 on the total sample could be "excessive" in the top 25 mm of the layer – and so adversely affect the average PI and the acceptability of the layer after construction. This phenomenon probably has also contributed to the perception that "fresh" dolerite decomposes/deteriorates rapidly in a constructed dolerite layer.

Furthermore, when constructing a G1 or G2 base, for instance, from dolerite rock the remaining fines (minus 0,075 mm fines not slushed out during the final aggregate interlocking phase) at the surface or filling the voids near the surface of the layer will contain more readily accessible clays, if present in the rock. Bearing in mind that although double seals are generally regarded as flexible, they are no longer flexible at temperatures below 3˚Cto 4˚C and can crack under heavy wheel loads, resulting in ingress of water into the base and lower layers. Smectite clays can take up approximately 70% of its own volume of water; and this expansion can disrupt the high density integrity of a G1 layer, especially where the minimum temperatures can drop to below minus 10˚C, causing frost heave, de-bonding between the surfacing and the base, and consequent disruption of the layer integrity and pumping of fines.

Thus, if it is decided to win and process "fresh" dolerite for the production of G1 and G2 quality material (or even G3 to G4 material), the following is recommended:

- Do X-Ray Diffraction analyses on samples to determine the quantity of mineralogical clays present.
- If the clay content is in excess of 3% it is recommended that 1% to 1.5% of lime be added to the crushed aggregate at the plant (the optimum dosage rate can be determined by ICL test). This should be done in order to reduce the PI to "non-plastic" and maintaining it by virtue of creating an alkaline environment (pH ≈ 12.4) in order to neutralise any clays that may become exposed to the elements by future mechanical breakdown – not to "stabilize"/cement it.

Incidentally, the addition of lime will also assist in drawing the fines to the surface during the slushing process in Crushed Stone bases, especially if the material should tend towards being slightly deficient in fines (a tendency observed in dolerites).

3.5 Myth 5: "Lime stabilization is not permanent"

The meaning of the word "permanent" according to the Oxford Dictionary is "lasting or meant to last, not temporary". According to the evidence perceived in the field, there is no question about the "lasting" qualities of lime stabilized doleritic material or remotely qualifying to be regarded as a "temporary" form of construction. It is the authors' opinion that the word "permanent" was loosely used to infer that the lime stabilized material would revert to the original gravel and probably break up in the process. For the lime stabilized dolerite samples to revert to the original gravel, the original chemical base-exchange that took place would have to be reversed chemically and for this to occur would require a chemical reaction which appears to be a most unlikely occurrence - which has been practically demonstrated in the above examples. In fact the chemical reactions which have taken place by pozzolanic reaction, and probably carbonation, has enhanced the permanency of the lime stabilization taking place over an extended period.

The authors have inspected numerous provincial roads over the past year, some serving heavy coal traffic, built 20 to 40 years ago with lime stabilized bases and sub-bases (750 – 1500 kPa design strength) and still giving excellent service – refer to Figures 2e and 2f. Base course and shoulder samples from all these roads were cored/cut out and are on display at the CSIR – all relatively fine to medium grained and very much intact. Laboratory tests show their present UCS strengths to be much higher than the design goal, whether surfaced or unsurfaced. (Incidentally, the PI's of the original material ranged between 8 and 17.)

Old-timer "padmakers" knew that a percent or two of lime could change a troublesome/marginal dolerite material into durable sub-base and even base quality material. However, doing a seven-day or even eleven-day (as prescribed by some road authorities) unconfined compressive strength (UCS) test on a lime stabilized soil will most probably result in misleadingly low values, despite the immediate dramatic increase in CBR value.

Keeping the above in mind, the importance of assessing the effect and effectiveness of a lime on a specific material by way of laboratory tests (CBR, CBR/swell, ICL, UCS, Durability Mill, PI/lime ratio, etc.) is clear – especially where it concerns upper pavement layer work. In this way, one may be able to assess the behaviour and probable performance of the treatment and select the most appropriate action for the prevailing conditions. The technique of treating basic crystalline material with lime, as well as extending the laboratory "curing" time prior to strength testing and before adding more/other stabilizer for “strength” purposes, if still necessary, has been applied by some road authorities for many years.

The demands on base and sub-base courses have been increasing steadily, necessitating increased pavement bearing capacity – which has been addressed mainly by stabilising the base and sub-base gravel. And so stabilization for immediate strength purposes (without regard for structural strength-balance) became a cure-all in some quarters, inter alia allowing poorer quality materials to be used, resulting in more load and environment sensitive pavements. In so doing, immediate initial strength of the base became the focus (as if the initial traffic-load would necessarily require the full design bearing capacity) and sight is lost of the original aim of achieving long-term pavement bearing capacity, balance and durability.

From the roads inspected and the samples taken, as mentioned above, it is clear that sufficient strength can be developed to enable the pavement to perform very well over an extended period with dolerite having a PI ranging from below 8 to 17 – refer to Figures 2e to 2h – also putting to rest the myth that lime only works well with dolerite that has a “high” PI.

Possibly because of this difference in behaviour between lime and cement stabilized material, old-timers have it that lime treated roads have self-healing properties (small stress/strain cracks in lime stabilized material tend to mend with time) and grow old more gracefully than cement stabilized roads.

3.6 <u>Myth 6: “Stabilized dolerite is prone to detrimental carbonation”</u>

Detrimental carbonation is the forming of a powdery loose layer/structural disintegration after the layer has been chemically treated and compacted (Paige-Green et al 1990). This phenomenon allegedly occurs in both cement and lime stabilized dolerite (basic crystalline rock) if the layer is not cured/kept damp until being covered or surfaced. From the limited number of case studies of projects that were recently investigated and work that Botha (2005) reported on quite extensively, where detrimental carbonation was claimed to have occurred, the salient features that were observed by the authors are:

- The gravel being treated/stabilized was weathered/”soft” dolerite and in one case weathered granite.
- The material contained clay minerals (from extensive work already done on dolerite it could be concluded that the material contained a certain quantity of smectite).
- The stabilizing agent in all cases was cement.
- The layer was not sealed off from the atmosphere (CO2) as soon as possible after compaction.
- The layer was not kept damp until primed/surfaced. (Watering of the base after compaction has been completed is difficult to achieve on an efficient regular bases.)
- There is apparently no logical agreement between the “authorities” on the true cause of “destructive carbonation” e.g. according to Botha’s work it is not caused by free access to CO2 but is “water driven”. Botha effectively with tests proved this in the laboratory.

Furthermore, the manifestation of a powdery/loose layer at the top of a stabilized layer should not automatically be ascribed to “detrimental carbonation”. One or more of the following activities could also be the cause:

- Working the material beyond the stabilizer setting time.
- Workmanship – basically poor/inadequate mixing procedures of the stabilizer.

- Effecting level corrections with untreated or “dead” material from windrows.

Borrow-pit variability not observed and effectively addressed.

From the observations of the roads inspected (lime and lime/slag stabilized dolerite gravels, both in the exposed shoulders and surfaced base layers) there is no evidence of detrimental carbonation. On the contrary the shoulders appeared to increase in strength (assisted probably by carbonation). While keeping a stabilized layer consistently damp until sealed is virtually impossible, according to enquiries and the authors’ experience it is not at all critical for lime treated bases to be kept damp until surfacing occurs.

From all accounts it seems that the normal setting process wherein the material gains strength is upset by the expansion of the, now exposed, clayey components of the material in the presence of water – especially prevalent in basic crystalline rock/gravel. This process has also been investigated by Botha (2005) and, although not yet fully understood, observed to be (free) water driven. In other words, indications are that wet-dry cycles such as regularly occurs under construction curing would exacerbate the manifestation of “detrimental carbonation”. This process would of course be assisted by high temperatures and low humidity.

Since the cementing process of cement requires a certain moisture regime for optimum results the procedure for testing stabilized samples in a laboratory include a curing phase (keeping the sample at a specific humidity and temperature). Hence it came about that this procedure has to be replicated in practice for optimum results. However, one knows that it has always been problematic, to say the least – it is seldom possible to keep the layer at a consistent humidity/dampness for a week, even under the most favourable weather conditions. This practice has proven to be only variably successful in practice and very dependant on the area and its weather conditions. None-the-less, this was considered better than doing nothing – which, with the knowledge now available, does not quite seem to be so.

The following observations have been made by the authors over the years regarding detrimental carbonation:

- Preferably use lime as a stabilizer if its efficacy is indicated by laboratory tests, especially with dolerites.
- Prime and surface the base as soon as it is dry enough (this can be within a day or two in very hot and dry climates) to assist in sealing the newly stabilized layer off and so stabilize the moisture regime seems to be most effective against detrimental carbonation. However, the rock hard lime stabilized and unsurfaced shoulders of the old roads, mentioned earlier, pertinently mitigates this being necessary with lime stabilization. In the opinion of the authors, and with reference to their investigation and the many lime stabilized dolerite samples on hand, it would be better to let a lime stabilized dolerite layer dry out under natural conditions, only sufficiently to apply the prime/surfacing.

4. CONCLUSIONS

It is concluded that the myths surrounding the use of dolerite for road building purposes can be dispelled as just that, based on a lack of knowledge of the material and its application. Properly assessed and appropriately applied, there is no reason to avoid using weathered dolerite in the base and sub-base layers of very light to medium bearing capacity pavements (below 2 MISA).

5. ACKNOWLEDGEMENT

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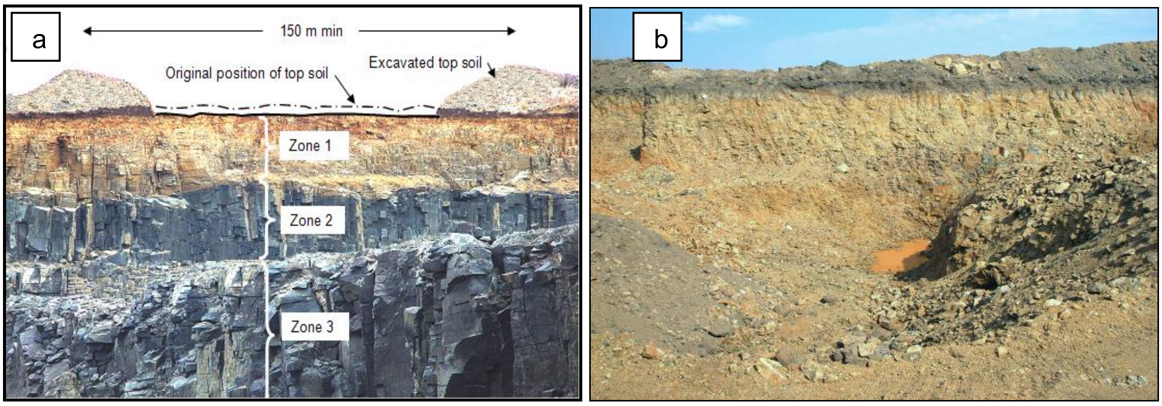

Figure 1: Examples of a dolerite quarry showing weathering zones and a typical “Zone 1” borrow-pit.

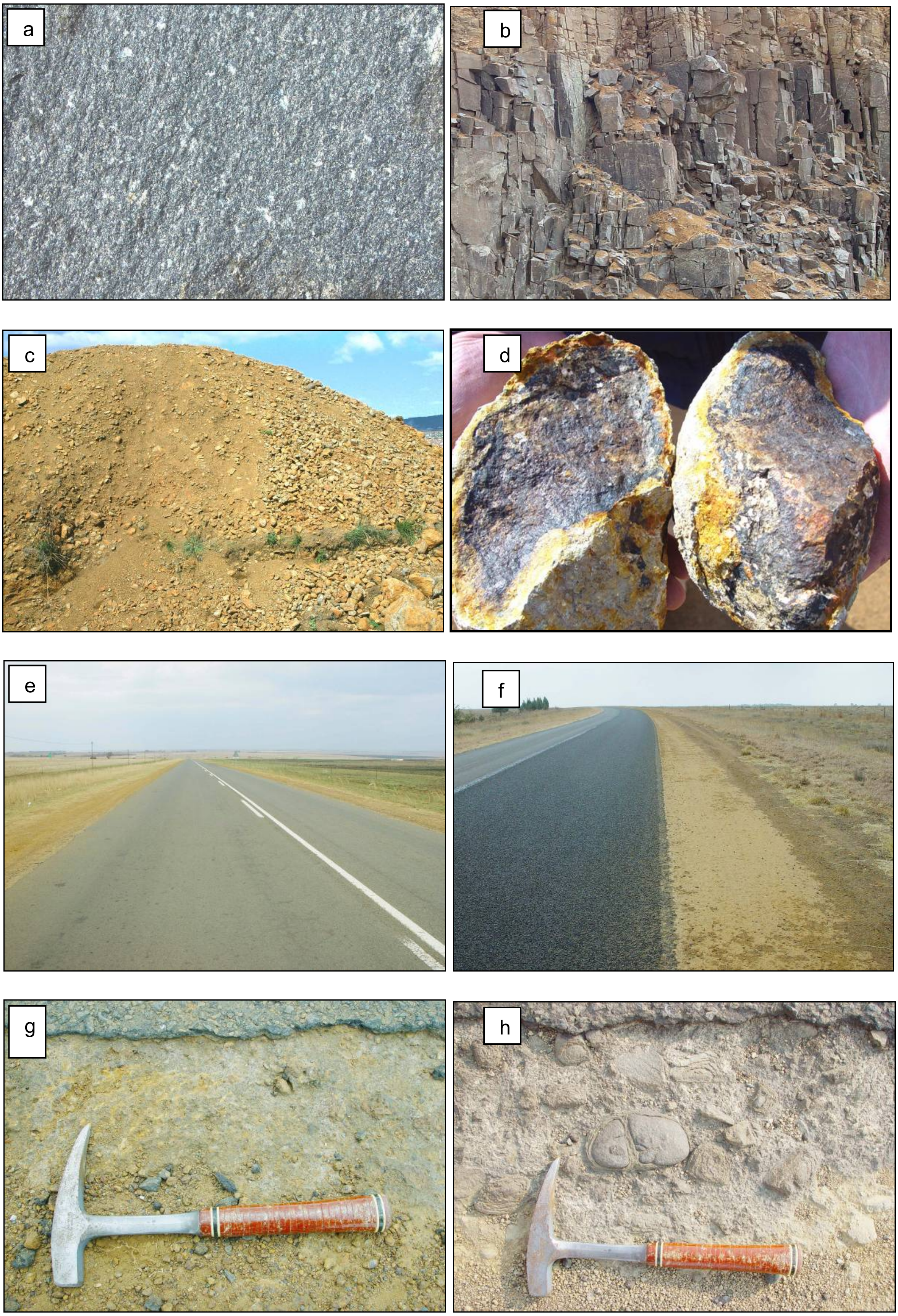

Figure 2: Examples of fresh and weathered dolerite, long serving lime stabilized dolerite pavements and exposed shoulder conditions.