Building-stone resources in Eritrea: results from introductory work in the NGU-EGS co-operation programme

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Several building-stone quarries and prospects in Eritrea were visited during September 1998, as a part of the Norwegian-Eritrean ERINOR co-operation project. The bedrock geology of Eritrea comprises a variety of rocks, of which Proterozoic granitoids and marbles are, at present, considered to be most interesting for building-stone production. Neither the marble deposits nor the granitoids visited are of such exclusive quality that they would obtain high prices on the international dimension-stone market. However, several deposits seem to be of excellent quality for low-cost production of slabs, tiles and other products, and thus represent an interesting resource for domestic processing.

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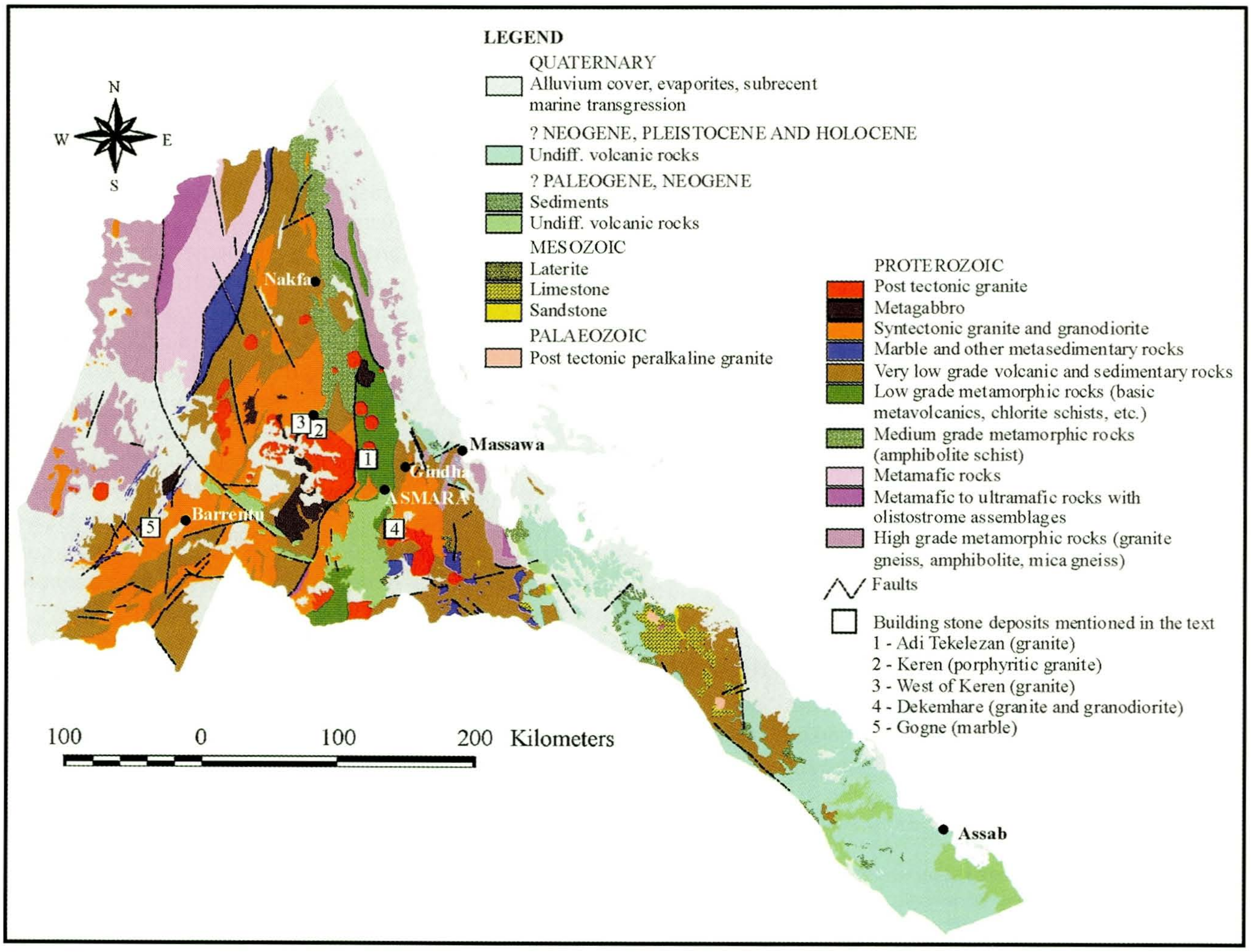

Fig. 1 Simplified geological map of Eritrea and localisation of building-stone deposits described in the text.

Introduction

In spite of its relatively small size, Eritrea exhibits a diversified geology which can generally be grouped into three main lithological assemblages. These are Precambrian metamorphic and igneous rocks, Mesozoic sedimentary rocks and Cenozoic volcanites and sediments (Fig. 1; Kazmin 1972).

The metamorphic basement, belonging to the Arabian-Nubian shield, covers a major part of the country. The Precambrian of Eritrea includes a variety of lithological units, ranging from high-grade (Archaean?) gneisses, low- to medium-grade, volcano-sedimentary successions of Neoproterozoic age to pre-, syn- and post-tectonic granitoid intrusions of Neoproterozoic age.

Although the Palaeozoic era was characterised by peneplanation and virtually no sedimentation, transgression of the Indian Ocean led to deposition of sandstone and limestone successions in Mesozoic times. This was followed by uplift and subsequent development of a thick, lateritic weathering profile. During Early Tertiary time, an extensive period of volcanism was initiated, starting with the plateau basalts of the Trap Series and followed by several events of rift related volcanism and sedimentation.

Regarding building-stone, both marble and granite have been exploited industrially since the Italian colonial period. In parts of the country, there are strong traditions of using stone for local housing, especially granite, slate, limestone and volcanic rocks[1]. After Eritrean independence in 1993, a national stone industry was established, and a sophisticated processing plant for dimension-stone, located in the town of Gindha, is now producing tiles and slabs for the domestic market. Several marble and granite deposits are now being exploited and prospected throughout the country. There are, however, few geological reports covering building-stone resources in Eritrea. A brief introduction to the subject however, was given by Bradley (1995).

As a part of the Norwegian-Eritrean ERINOR project[2], several deposits were visited during September 1998 (Fig. 1). A national inventory of such resources is expected to become a part of the Eritrean Geological Survey's activities in the years to come. In this article, a description and preliminary evaluation of some of the most important building-stone deposits is given, including the marble deposits near Gogne in SE Eritrea and granitoid deposits south and north of the capital, Asmara.

Industrial and market considerations

Dimension-stone differs from other types of mineral resources by the variety of its uses and markets. Stone products of excellent quality may readily be produced using simple tools and manpower, although the mining and processing may equally involve the use of highly sophisticated machines. Applications vary from crudely shaped blocks for local housing to polished slabs cladding skyscrapers in the cities around the world (Shadmon 1998).

For small-scale, *local housing* production of stone, it is important that the rocks can be easily worked with a minimum of labour, and that the deposits are found close to where the stone is used. In Eritrea, we find examples of such production of granite (South-Central highlands), basalt (Central Highlands) and coral reef limestone (East Coast). These deposits share a common feature, in that the rocks can be split or cut easily into cubic or roughly shaped blocks.

Raw block export is the most common way of getting access to the international market for dimension-stone. The blocks are mainly sold to countries which have a large stone-processing industry, like Italy, Spain, Portugal and some countries in the Far East (Conti et al. 1990). A standard size for trade blocks is 2.4 x 1.2 x 1.0 m (ca. 8 tonnes). Most suppliers will be asked for even bigger sizes, up to 30 tonnes, to feed the big frame saws in Italy or elsewhere. However, the need to move such heavy pieces of rock makes demands for sizeable investments in quarry machinery.

The blocks should be well-shaped with no veins, cracks or inclusions. For small blocks and blocks with such imperfections, the price may be reduced by 50% or more. Prices of raw blocks are, furthermore, highly dependent on the colour and structure of the stone; rare colours such as blue, pure white, pure black, yellow and emerald green can demand considerably higher prices than more ordinary colours (see also Walle et al., this volume).

The international market for *finished products* works differently. Here, the customers are either the end-users of stone products or stone traders. The largest markets for finished stone in the world are USA, Japan, the Middle East, North-Central Europe and some Far-East countries. Although the prices for rough blocks vary a lot according to stone type, size, shape and quality, finished products show fewer variations, due to the 'smoothing' effect of the quite significant costs of stone processing. There is, however, an increasing tendency for consumers to demand quality control systems from the supplier, and the latter should at least be capable of meeting the international standards on size and flatness deviations, uniformity, polish, etc. As a result, advanced processing machinery becomes a necessary investment for those who would like to begin exporting finished stone.

In most countries, including Eritrea, there is a market for tiles and slabs for local construction. In general, tolerances on uniformity and other technical specifications are somewhat wider than for export products, due to the customer's preferences for local material.

The logistics connected with exploitation of building-stone (quarry technology, infrastructure) thus depend on the intended market. For local housing and construction, it is important that the extraction costs are low, necessitating the need for rock types with excellent workability properties. For export markets, the colour, pattern and block size are much more important. During regional investigations of the

1. Such traditions are also known from the Ethiopian highlands, see Walle et al. (2000).
2. The ERINOR project is aimed at increasing the Eritrean Geological Survey's (EGS) capability of investigating the country's mineral resources, and involves institutional co-operation between EGS and NGU in different fields related to geological mapping and evaluation of mineral deposits.

dimension-stone potential, focus should therefore be placed, at an early stage, on the market potential for the different rock types. In this article, we present a preliminary evaluation of market aspects, as well as of the technical quality of rock types and deposits, based on field relations and by comparing the deposits with other rock types on the international market. Testing of physical properties has not been carried out, but will be a natural part of more detailed, follow-up studies of deposits.

Eritrea has, in contrast to many other African countries, a relatively good infrastructure with roads providing access to large portions of the country. Port facilities on the Red Sea coast potentially offer rapid access to international markets.

Marble deposits

Marble occurs within the Proterozoic metasedimentary successions, and the marble-bearing units are present two distinct zones. The western zone defines a NNE-SSW striking belt from the southwestern corner of the country towards the Sudanese border in the far north (Fig. 1). Marble deposits are known from the southwestern (the Gogne area) and central parts (the Akordat area; Bradley 1995). In 1998, the former area was included in the preliminary investigations. Another zone occurs between Dekemhare and the Ethiopian border (Fig. 1), and deposits are known in the Debri and Kerzekerte sub-areas. The Eritrean marbles are essentially fine- to medium-grained, calcitic and of low regional metamorphic grade. In the western zone the marbles comprise several colour varieties, from pink and white to grey and black, while predominantly grey and black types are described from the eastern zone (Bradley 1995).

The Gogne marble deposits occur within a mica schist unit close to the small town of Gogne in southwestern Eritrea. The metasediments are locally intruded by a pre- or syntectonic gabbro. One company (MarGran) has several quarries in the marble deposit, most of them at a trial stage. The blocks are transported by truck to the factory in Gindha. A new road is under construction, and in the near future most of the distance to Gindha will be paved surface.

The marble deposit consists of intercalating, steeply dipping layers of several commercial types, of which the most common is grey with white veins. Other types include white marble with grey and black veins (Fig. 2), black with white veins and impure, silicate-bearing pink marble. These subtypes generally occur in thin layers, not exceeding 10-15 metres, but the layers may locally be thickened in fold-hinge zones. The marbles are essentially fine- to medium-grained, but are locally coarse-grained, especially approaching the gabbro. Thus, the increased grain size may be a local effect caused by thermal metamorphism related to the intrusions. Joints are generally closely spaced in the area, especially in the deposits close to the gabbro, where problems have been experienced in obtaining commercially sized blocks. Here, filled joints are also very common, giving a network of black and white veins on polished slabs.

Fig. 2. Prospect of white calcite marble in the Gogne area, SW Eritrea. Diamond wire has been used for vertical cutting.

Considering the Gogne area as a whole, the possibility of exploiting several commercial types of marble within a limited area makes it interesting as a dimension-stone prospect. Some of the varieties, especially pure white and black marbles, may be of interest for export markets, whilst the grey and pink varieties are expected to fetch low prices and meet strong competition from a number of marble-producing countries. The main geological challenge would be to localise parts where the incidence of jointing is less, and to obtain more detailed information about the size and geometry of the different commercial layers. This will involve detailed field mapping combined with studies of aerial photographs. There is a particular need for an interpretation of the structural pattern, localising fold-hinge areas where the probability of finding thick and massive deposits is considered to be greater.

Igneous rocks

The bedrock geology of Eritrea comprises a variety of plutonic rocks of different ages, ranging from Proterozoic, pre- and syntectonic granitoids and gabbros to Late Proterozoic/ Early Palaeozoic granite, granodiorite and peralkaline granite post-dating the major Proterozoic deformation and metamorphic events.

The pre- and syntectonic intrusions occur essentially in the central part of the country, within a triangle defined by the southwestern corner of Eritrea, the Dekemhare area and the area north of Nakfa (Fig. 1). Rock types are predominantly gneissose to slightly foliated granites and metagabbros. Since the building-stone potential of metagabbros is rarely of particular interest[1], the focus has been on the granitoids. One such deposit was visited in 1998. This occurs slightly west of the town of Keren, and is targeted by the MarGran company as a possible object for future exploitation. The area is easily accessible on paved roads.

The granite is foliated, 'gneissose', and forms large peaks and hills in the area (deposit no. 3 in Fig.1). Boulder weathering is not common at this locality; rather, the hills have a mas-

1. Metamorphic gabbros are, in most cases, highly fractured and contain retrograde mineral assemblages, causing the rocks to be of considerably lower value on the dimension-stone market than their non-metamorphic equivalents.

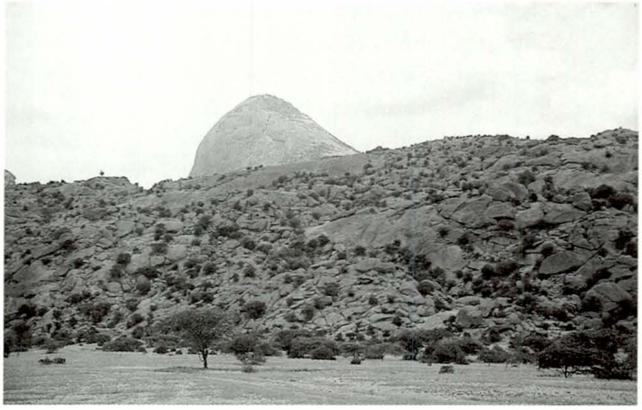

Fig. 3. Exposures of hill-forming, pre-tectonic granite to the west of Keren.

Fig. 4. Outcrop of pre-tectonic granite west of Keren. Note aplitic veins and nearly horizontal exfoliation along foliation planes.

Fig. 5. Split surface of boulder of fine- to medium-grained granite close to Dekemhare. Note wedging holes made by hammer and chisel and stained weathering profile (approximately 7-8 cm in thickness).

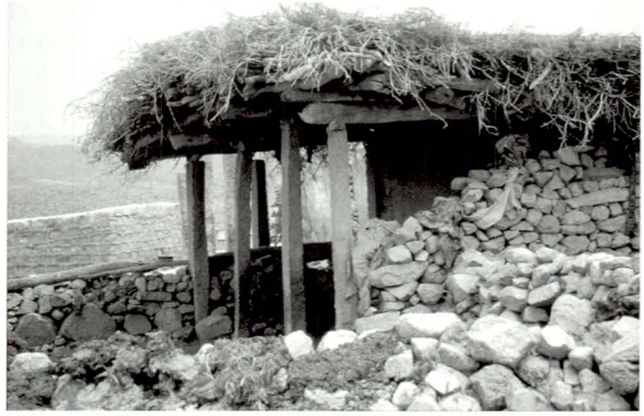

Fig. 6. Granite columns used in local houses near Dekemhare.

Fig. 7. Vertical split surface in giant boulder of granite close to Dehemhare. Note toolmarks on the top of the boulder.

sive and rounded appearance (Figs. 3 and 4). The granite, at the studied locality, is medium- to coarse-grained, grey to pink, and the nearly horizontal foliation is defined by oriented micas and aggregates of quartz and feldspar. The content of microfractures seems to be high, and because of this, the granite has a deep, stained weathering profile. Thus, one would expect that both water absorption and permeability would be higher than the average for granites. Such microfracture patterns are quite common in foliated pre-tectonic granites, and probably represent a 'proto-cataclastic' response to medium/low-temperature strain. This texture could also be the reason for why weathering attacks microfractures and grain boundaries rather than joints, so that the typical boulder weathering that is common in more 'sound' granites does not form. The granite contains abundant aplitic veins and biotite-rich inclusions. Both these features and the foliation development might possibly decrease towards the central part of the granite (we were only looking at the marginal part), and for further investigation one should pay special attention to these central parts. Such granites are cheap materials on the international market, and, furthermore, granites containing abundant microfractures could sometimes be too 'soft' and permeable for the production of thin slabs for use as tiles. On the other hand, they generally have excellent splitting properties and may be very usable for split-stone for local housing and paving stone. Sporadic production from similar granites is known from northern Norway; other comparable types on the market include 'Rosa Delicato' and 'Ara Cinza' (Brasil).

Post-tectonic granitoids occur in several places around the country, varying from fine- to medium-grained granites and granodiorites, through porphyritic granite to the younger, peralkaline granites in the southwestern part of Eritrea (Fig. 1). The latter type has not yet been investigated as a source for building-stone.

Occurrences of fine- to medium-grained granitoids are known from a number of localities. Approximately midway along the road between Asmara and Keren (deposit no. 1 in Fig. 1), there is a circular shaped granitic pluton of predominantly grey, medium-grained granite. Along the roadside, the granite is partly altered to green saussuritegranite. This green colour is considered to be interesting in the dimension-stone market[1], and the granite has been sampled by MarGran. However, the spacing of joints is tight, making the extraction of commercial-sized blocks difficult. The reason for this is that the alteration of the granite is probably associated with either fracture zones or the pluton's marginal zone, both areas where highly fractured granite should be expected to occur. Furthermore, fine-grained pyrite is abundant in the granite, causing rusty staining even on quite fresh surfaces.

Fine- to medium-grained pink granite (Fig. 5) and grey granodiorite cover a large area close to the town of Dekemhare (deposit no. 4 in Fig. 1), easily available by paved road. Boulder weathering is common. These granitoids have for a long time been subject to traditional extraction by simple tools for local housing (Fig. 6). Both the ongoing quarrying activity and houses in the area bear witness to the excellent splitting properties of these rocks. Even with simple tools like a hammer, a chisel and some plugs, one can split 4 metre high boulders (Fig. 7). With the introduction of slightly more advanced industrial methods, and good knowledge of granite 'rift' and 'grain', it should be possible to produce large volumes of blocks and other granite products (kerbs, paving-stones, etc.) at low unit cost. Joint spacing varies in the area, and there are scattered, small hills with a wider joint spacing than the surroundings. Further investigations should focus on these prospects.

The Dekemhare granites are quite exceptional in the way that a wide range of granite products, from polished slabs to kerbs and bricks, can be produced at a low cost and with low investment in quarry technology. However, such granites and granodiorites are generally low-price products on the raw block market. Other, similar types on the international market include several varieties of Scandinavian, Spanish and Portuguese granites.

1. According to MarGran representatives and NGU's experiences with similar rock types in Norway.

Fig. 8. Porphyritic granite close to Keren. The largest phenocrysts seen on the photo measure approximately 5 cm.

Fine- to medium-grained, pink granite similar to the Dekemhare type also occurs in the Nefasit area (Bradley 1995), between Asmara and Gindha, and pilot quarrying has been carried out by MarGran.

Several deposits of porphyritic granite are known, including those in the Keren and Adi Quala areas close to the Ethiopian border south of Dekemhare (Bradley 1995). The former deposits were visited during the 1998 fieldwork, and a paved road passes through this circular shaped pluton (deposit no. 2 in Fig. 1). The granite is slightly foliated with large (up to 7cm) pink to grey feldspar phenocrysts (Fig. 8), and is reminiscent of certain other porphyritic granites on the market (Müller 1990), such as 'Rojo Villar' (Spain), 'Anger Guten' (Ethiopia), 'Texas Pink' (USA). The abundance of phenocrysts and their colour vary, particularly perpendicular to the foliation plane. Assimilated xenoliths and biotite-rich lenses and pockets are quite common; aplite and pegmatite veins occur sporadically. In the area, there seem to be several interesting prospects, especially within less jointed 'pockets' of granite forming small hills of boulder deposits. It is, however, important to pay special attention to the features influencing the homogeneity of the granite, such as the distribution of phenocrysts, xenoliths, veins and pegmatites, in any further investigation, since these may vary significantly over short distances.

Other rock types

There are several other rock types in Eritrea that could be of potential interest as building-stone. The large occurrences of low-grade pelitic rocks within the Proterozoic successions include deposits of black slate, but the quality of such deposits for industrial exploitation is not yet known. Within the ultramafic complexes in the northern part of the country, an obvious target for future investigations would be green serpentinite and soapstone.

For local construction, both limestone and volcanic rocks are extensively used. The town of Massawa, for example, is almost completely built of coral reef limestone from nearby deposits. Basalt and diabase dykes are quarried at a number of places in the Central Highlands, and there should be possibilities of finding tuff and ignimbrite deposits. Such resources represent a considerable potential for low-cost supply of an excellent construction material, and could be further developed.

Conclusions

On the background of the small number of deposits visited during the 1998 fieldwork and basic knowledge of others, it may be concluded that the bedrock geology of Eritrea can offer a variety of rock types of interest as sources of dimension-stone. However, few of these would clearly be considered as exclusive and therefore will not demand high prices on the international market. On the other hand, several of the deposits have excellent properties that make them suitable for the production of a wide range of stone products at low cost, both on an industrial scale and for local housing.

In this context, the national stone industry's strategy of processing a variety of Eritrean rock types for domestic and, on a longer term, international markets raises interesting perspectives for the exploitation of a number of deposits on a small-scale basis. Especially the marble deposits in the southeastern and southwestern part of the country, as well as several of the post-tectonic granitoids, would, in the short term, make the most obvious resource potential. In the longer term, development potential exists for several other rock types. Finally, the extensive distribution of both 'soft' and 'hard' rocks that can be extracted and processed with simple technology could contribute significantly to the country's future requirements for cheap construction materials.

In the future, EGS can have an important role in the evaluation and characterisation of dimension-stone deposits. This includes the characterisation of rock units during regional mapping (colour, texture/structure, joint patterns, general appearance), sampling and detailed investigation of deposits in co-operation with the stone industry. In addition, the EGS laboratories can be helpful with petrographic examinations and testing of physical properties, especially if the laboratories are equipped with facilities for the testing of bending and crushing strength.

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