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PRELIMINARY INVESTIGATION OF CEMENT MATERIALS IN THE TAIF AREA, SAUDI ARABIA

by

Conrad Martin
U. S. Geological Survey

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PREFACE

In 1963, in response to a request from the Ministry of Petroleum and Mineral Resources, the Saudi Arabian Government and the U. S. Geological Survey, U. S. Department of the Interior, with the approval of the U. S. Department of State, undertook a joint and cooperative effort to map and evaluate the mineral potential of central and western Saudi Arabia. The results of this program are being released in USGS open files in the United States and are also available in the Library of the Ministry of Petroleum and Mineral Resources. Also on open file in that office is a large amount of material, in the form of unpublished manuscripts, maps, field notes, drill logs, annotated aerial photographs, etc., that has resulted from other previous geologic work by Saudi Arabian government agencies. The Government of Saudi Arabia makes this information available to interested persons, and has set up a liberal mining code which is included in "Mineral Resources of Saudi Arabia, a Guide for Investment and Development," published in 1965 as Bulletin 1 of the Ministry of Petroleum and Mineral Resources, Directorate General of Mineral Resources, Jiddah, Saudi Arabia.

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ABSTRACT

A preliminary investigation of possible sources of cement rock in the Taif area was made during the latter part of August 1968. Adequate deposits of limestone, clay, quartz conglomerate and sandstone, and pisolitic iron ore, yet no gypsum, were located to support a cement plant should it prove feasible to establish one in this area. These materials, made up mostly of Tertiary and later sediments, crop out in isolated, inconspicuous low hills in a north-trending belt, 10 to 15 kilometers wide, lying about 90 kilometers to the east of At Taif. The belt extends for more than 90 kilometers from the vicinity of Jabal 'An in the south to the crushed rock pits at Radwan and beyond in the north. The area is readily accessible either from the Taif-Riyadh highway or from the Taif-Bishah road presently under construction.

The limestone, which is quite pure and dense in some localities but dolomitic, argillaceous, and cherty in others, occurs in a variety of colors and would make a suitable decorative building stone.

The volcanic rocks of the Harrat Hadan, lying directly to the east of the limestone belt, include volcanic ash beds some of which may have been altered to bentonitic clays. Others may have been lithified and might be suitable for light-weight aggregate. These possibilities remain to be investigated.

Precambrian metamorphic rocks lying directly to the south and southeast of Taif were also investigated as possible cement rock sources, but no suitable material was found here.

INTRODUCTION

Limestone, sandstone, and clay are the principal raw materials, but by no means the only ones, that enter into the manufacture of cement.

The essential ingredients of Portland cement are lime (CaO), silica (SiO_2), and alumina (Al_2O_3), roughly in the ratio of 6:2:1. Iron oxide is generally also present, taking the place of some of the alumina. In applications where a low heat of hydration is desirable or where resistance to the activity of sulphate solutions is a consideration the proportion of iron oxide may be equal to or even exceed that of alumina. In white cement, on the other hand, the iron oxide content is generally kept below .5 percent.

Gypsum to the extent of 3 percent is usually ground with the cement clinker or added at the point of use. Its purpose is to regulate the rate of setting of the concrete to reduce the rate of heat generation and to increase its ultimate strength. Small amounts of a reactive silica such as ground opaline chert or volcanic ash may be added to counter the effect of excess alkalies. In the production of white cement ground fluorite is added as a fluxing agent to facilitate the burning and clinkering process. Characteristics such as quick-setting or early strength are obtained by small changes in the proportions of the principal ingredients, by carefully controlled burning conditions, and by the finess of the ground clinker.

Magnesia (MgO) is undesirable in Portland cement and is usually limited to less than 5 percent. Some natural cements may, however, contain as much as 20 percent magnesia. These are used mostly in mortars in which their greater plasticity and workability give them a decided advantage.

The alkalies (Na_20, K_20) are also deleterious because of possible reaction with the aggregate of the concrete. They are usually kept as low as possible but amounts up to 2 percent or so are tolerated.

The ideal cement rock would be a combination of limestone, sandstone, and clay, low in magnesia and alkalies, which when calcined would contain the essential ingredients - lime, silica, and alumina and iron in roughly the ratio set out above. Some marls approach this combination but these are so comparatively rare that the search for cement raw materials is generally focused on finding diverse deposits, located not too far from each other, the materials of which can be blended to achieve the desired composition. The deposits should also be located within a reasonable distance of transportation, labor, power, water, and supplies, and not too far from the principal markets.

The foregoing considerations guided the present investigation which was carried out between August 18 and 28, 1968. Abdullah Ankary, Ministry geologist, accompanied the writer. Miseri Maitek and Omar Bajinet acted as guides and drivers. Analyses were made at the Jiddah laboratory of the Ministry of Petroleum and Mineral Resources. The procedures used give only approximate results. These, however, are adequate for the purpose in hand. In most instances the variation lies within 10 percent of the values reported. In some cases the variations may be as much as 20 percent, rarely greater.

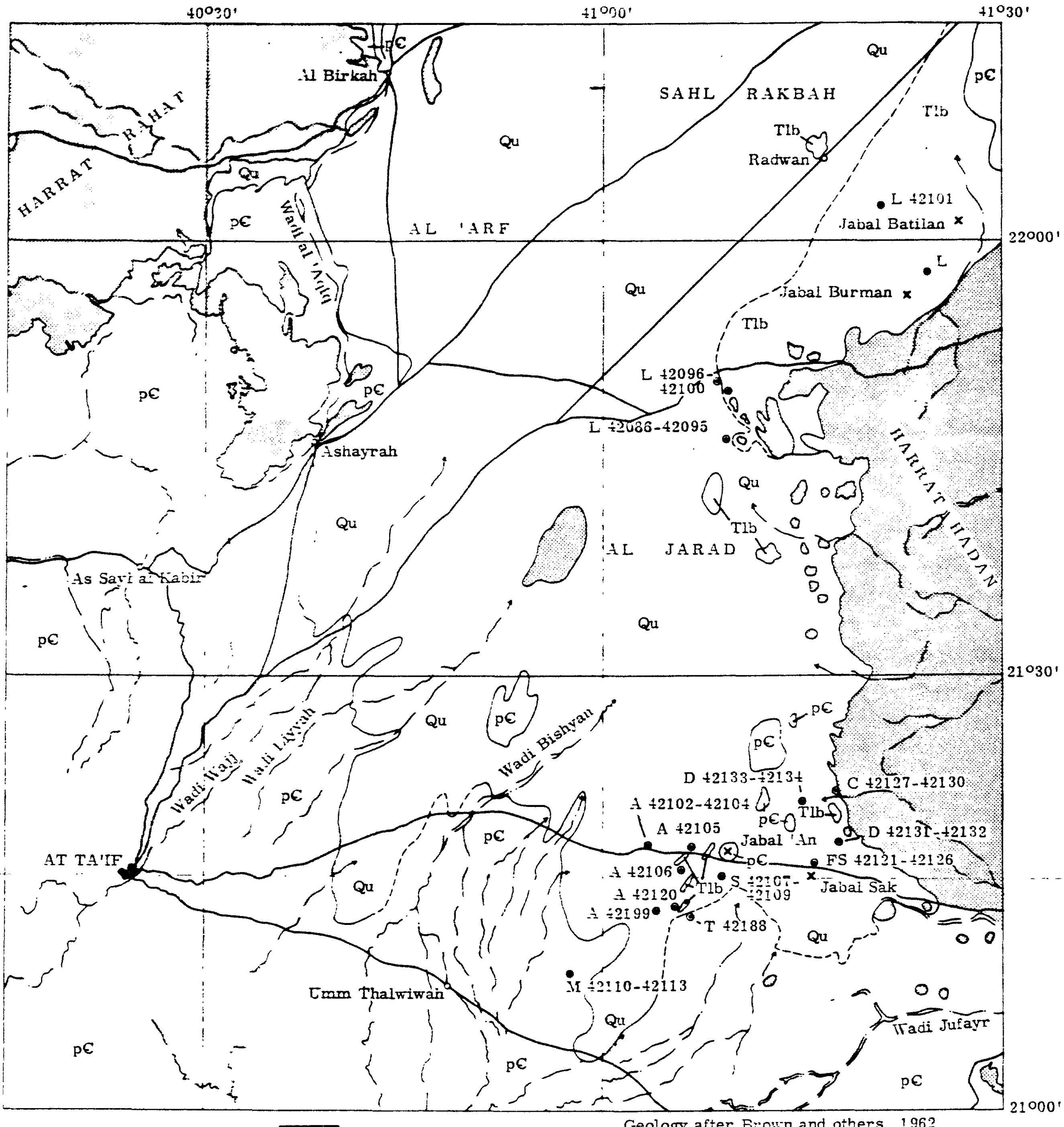
LOCATION AND ACCESSIBILITY

The area of principal interest lies roughly between lat. 21°15' and 22°15'N. and long. 40°30' and 41°30'E. (fig. 1). Taif is located just outside the southwestern corner of this area near the western edge of the Hijaz plateau at an elevation of 1680 meters. From here the pediments and the plain of Al Jarad slope gently to the north and east. The drainage converges into this area from the dissected igneous and metamorphic terrain bordering the upraised lip of the plateau lying to the south and west of Taif, and from the rugged western front of the Harrat Hadan lying to the east. Although the Al Jarad is open both to the north and to the southeast, there are no major through-coursing wadis. Sand movements is minimal being stabilized by a sparse vegetation. Annual rainfall may be about 15 cm.

The Jiddah-Riyadh highway passes through Taif. A modern highway is presently under construction which will greatly facilitate communication between Taif and Bishah. Numerous desert tracks make most of the area readily accessible by vehicle.

GEOLOGIC SETTING

The geology of the area has been set out by Brown and others (1962), as well as by Goldsmith (in press). The following will, therefore, recapitulate only the salient features.



Qu

QUATERNARY ALLUVIUM
Undifferentiated gravel, sand, silt, and clay

QUATERNARY AND TERTIARY BASALT

Tlb

TERTIARY LAKE BEDS
Lacustrine, tufa-like limestone and chalcedony

pЄ

PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS
Undifferentiated

Contact, dashed where approximate

●42101
Sample location

A Argillite
C Clay
D Dolomite
F Iron
L Limestone
S Sandstone and/or conglomerate
T Tuff

10 0 10 20 30 40 KILO

FIGURE 1.- Geologic sketch map of the Taif area showing sample locations

The region around Taif is underlain mostly by granites and gneisses of Precambrian and possibly early Cambrian age. These enclose extensive remnants of intensely folded Precambrian metamorphic rocks consisting predominantly of sericite and chlorite schist, amphibolite schist, greenstone, argillite, and some small patches of coarse crystalline limestone. On the east, extending northward from Turabah and Jabal Sak, the area is covered by the Tertiary basalt and pyroclastic rocks of the Harrat Hadan. One finds here also remnants of later rhyolite and latite flows. The basalt and pyroclastic rocks of the Harrat Hadan overlie Tertiary carbonate rocks, pebble conglomerate, pisolitic ironstone, and other sediments which crop out sporadically in low hills that rise above the pediments and the alluvial plain of Al Jarad directly to the west. To the north and northwest the area is covered largely by Quaternary basalt.

LIMESTONE

The most promising source of lime is the north-trending belt of Tertiary carbonate rocks, 10 to 15 kilometers wide and more than 100 kilometers long lying about 90 kilometers to the east of Taif and directly to the west of the Harrat Hadan basalt. A number of traverses were made by vehicle across this belt between Jabal Saq in the south and the crushed rock pits at Radwan in the north. Within this belt, the flat-lying or gently-dipping carbonates crop out sporadically in inconspicuous low hills which rise but a few meters above the surrounding terrain. Much of the outcrop area is covered by alluvium and basalt rubble, but the exposures are sufficiently extensive to give an appreciation of the volume (which can be reckoned in the hundreds of millions of tons) and of the quality. The base of the carbonate rocks was nowhere encountered. The greatest exposed thickness is about 30 meters.

The composition ranges from almost pure limestone (analysis 42093) through dolomite (analyses 42131-42134). The range of compositions is given in Table 1 and the sample locations are shown on Figure 1. Dolomite crops out more often in the extreme southern part of the belt, while limestone predominates in the central and northern parts. Much of the material is siliceous - more so in the north than in the south - but the silica content, mostly in the form of chert and opal, rarely amounts to 6 percent. The average would be about 2 percent. Alumina and iron oxide are uniformly low, however, the more argillaceous material would be more easily eroded and therefore less likely to crop out. Sulfate minerals were not identified in the rock, so no analyses for sulfate were made.

The texture is usually fine grained, but it may range from porcelaneous to coarse granular. The rock is mostly dense and massive, but it may be porous or tufa-like in places. The thickness of the bedding differs considerably, but it generally lies in the range of from 10 to 50 centimeters. The lighter shades of gray and buff are the dominant colors, but white, black, light purple, and particularly lively yellowish-brown are also common.

Table 1 Approximate analyses of cement raw materials, Taif Area, Saudi Arabia.

Sample no	SiO_2	CaO	MgO	Al_2O_3	Fe_2O_3	Na_2O	K_2O	Ignition loss	Remarks
42086	5.8	48.0	.5	.3	.4			40.3	Limestone
42087	3.7	47.5	.8	.5	.4			40.3	Limestone
42088	2.6	48.2	8	.3	.4			41.7	Limestone
42089	1.0	49.2	1.0	.3	.4			42.4	Limestone
42090	2.7	46.2	3.1	.7	.4			42.3	Magnesian limestone
42091	5.0	45.7	5.1	.3	.4			41.0	Magnesian limestone
42092	2	51.6	1.2	2	.4			42.6	Limestone
42093	5	51.2	5	.1	.4			42.2	Limestone
42094	.7	52.1	2.6	.1	.4			42.9	Magnesian limestone
42095	.3	31.9	16.0	.3	.4			44.8	Dolomite
42096	2	49.0	1.9	.1	.4			43.8	Limestone
42097	3.2	47.4	1.0	8	.4			41.0	Limestone
42098	5.7	50.4	0.0	.8	.4			42.2	Limestone
42099	4.9	35.7	10.0	.7	.4			42.2	Dolomitic limestone
42100	2.3	48.6	6	.5	.4			42.1	Limestone
42101	10.4	41.9	1.8	1.4	.4			37.9	Cherty limestone
42102	86.0	5.4	.9	11.7	13.4	2.7	.3	2.3	Argillite
42103	49.5	7.4	7.4	13.3	10.3	.9	.2	5.4	Argillite
42104	43.3	5.3	3.1	14.8	13.7	3.6	.3	2.8	Argillite
42105	81.8	3.6		10.4	11.8	3.1	.8	4.1	Argillite
42106	39.0	2.3	3.1	12.1	13.6	3.5	.4	2.6	Argillite
42107	75.4	3.5	6	3.1	1.7			5.0	Conglomerate
42108	80.0	3.4	1.3	5.1	1.9			4.9	Conglomerate
42109	77.2	1.8	3	1.5	1.6			3.7	Conglomerate
42110	3	42.6	3.2	1.4	.9			38.0	Magnesian marble
42111	3	39.1	2.6	2.9	.4			34.0	Magnesian marble
42112	1.2	46.7	3.6	1.7	.4			42.3	Magnesian marble
42117	5.3	36.3	4.9	2.3	.6			34.6	Magnesian marble
42118	62.5	1.7	2	7.2	5.0	8.3	5.0	3.3	Latite tuff
42119	48.6	1.2	2.0	10.8	7.0	2.6	3.6	2.1	Slate
42120	41.3	2.3	2.0	14.2	7.2	4.4	1.2	2.9	Argillite
42121	27.6	3.3	3	7.0	38.3			14.0	Pisolitic ironstone
42122	15.2	3.9	.1	9.1	55.5			14.3	Pisolitic ironstone
42123	28.7	1.8	.3	5.7	40.5			10.4	Pisolitic ironstone
42124	22.6	1.5	.4	7.6	45.7			11.5	Pisolitic ironstone
42125	24.9	4.0	.4	7.9	35.4			12.7	Pisolitic ironstone
42126	72.5	.4	.8	3.4	1.4			1.7	Sandstone
42127	22.5	13.9	5.0	8.9	7.4	.4	.2	21.8	Calcareous clay
42128	5.0	32.3	1.5	1.6	1.4	.2	.1	39.1	Caliche
42129	28.0	9.8	5.3	12.3	10.9	.9	.1	25.5	Calcareous clay
42130	26.5	11.7	5.8	11.9	9.7	1.2	.7	20.8	Calcareous clay
42131	.3	20.6	24.3	.1	.9			44.4	Magnesitic dolomite
42132	3	26.8	19.6	.1	.4			45.7	Dolomite
42133	.5	27.3	18.6	.2	.6			46.5	Dolomite
42134	.1	26.0	18.4	.4	2.9			45.5	Dolomite

The variation in composition and physical properties of the carbonate rocks described above does not seriously affect their usefulness as a source of lime. Changes are gradual and can usually be taken into account in a well supervised quarrying operation. It can also be anticipated that large volumes of the rock will be fairly homogeneous so that quality control will require no more than the usual vigilance.

SILICA

In most cement operations the required silica is derived from the clay or shale added to supply the alumina. However, in some instances a better blend may be obtained by adding the silica separately. A layer of coarse quartz sandstone and pebble conglomerate of probable Tertiary age was encountered at two places in the area. Sandstone of undetermined thickness underlies the pisolitic ironstone at Jabal Sak (analysis 42126). The pebble conglomerate (analyses 42107-42109) crops out in a low hill which rises about 2 to 3 meters above the surrounding pediment, about 4 kilometers southwest of Jabal An. The material is poorly bedded to massive and dips gently to the east. It consists of quartz pebbles up to 3 cm in diameter set in a siliceous and aluminous carbonate matrix. The rock is well indurated and breaks across the quartz pebbles and only rarely around them. It contains between 75 and 85 percent silica. The outcrops at the two localities are probably parts of the same conglomerate member which elsewhere no doubt lies under the shallow alluvial cover.

CLAY, SILT, AND ARGILLITE

A variety of materials are being used as sources of alumina, but bauxite, because of its high alumina content is much preferred. By far the most common sources are clay and silt largely because they are more readily available and because they require little crushing or grinding. However, slate, argillite, diorite, anorthosite, gabbro, and other aluminous materials have also been used.

Because of the alluvial and rubble cover, the distribution of suitable clay and siltstone in the area of interest could not be determined without digging a number of pits which was not thought justified for the present purpose. A low ridge of silty clay, about 1000 meters long, 100 meters wide, and with 3 meters of relief, was encountered about 10 kilometers north-northeast of Jabal Sak preserved under a meter or so of basalt rubble and caliche. Similar material will no doubt, be found over a wider area under the thin rubble cover. Analysis 42128 represents the caliche, and analyses 42127, 42129, and 42130 represent surface samples of the clay. The magnesia content is somewhat high but not excessive and suggests that the clay may be a calcareous bentonite.

Argillites of diverse origin make up a large part of the Precambrian metamorphic rocks locally exposed in the bare pediment surface. They are steeply-dipping, north-trending belts a few kilometers to the west and southwest of Jabal 'An. The rocks are somewhat schistose but more often blocky. Colors range from dark-greenish-to slate gray. Analyses 42102 through 42106, 42119, and 42120 give the range of their compositions. The weathered surface is dark gray to brownish black rather than the reddish brown one would expect from the amount of iron reported. These are, of course, only approximate analyses and it is quite likely that the iron content may be somewhat lower and the alumina content somewhat higher than shown. All samples contain magnesia and soda as well as some potash, but in most of them the amounts are within tolerable limits. Argillites occur in sufficient volume for any foreseeable needs. However, as long as clay and siltstone are available, argillites are not likely to be used in the manufacture of cement except under special circumstances.

IRON ORE

A flat-lying layer of pisolitic iron ore about 5 meters thick is exposed for about 1 kilometer along the base of the northern flank of Jabal Sak (analyses 42121-42125). It is overlain by Tertiary basalt and rubble and rests on light-gray, indurated, coarse sandstone of undetermined thickness which elsewhere grades into quartz pebble conglomerate. The ore is a structureless, jaspery, brown ironstone made up to goethite sperules cemented by ironstone enclosing, and often replacing, rounded, porous pebbles and slivers of carbonate rocks. It appears to be a reworked bauxitic laterite so that the proportions of alumina and iron oxide may differ widely from place to place. Should this prove to be the case then the material might be a source of both iron and alumina.

Goldsmith (in press) has reported the occurrence of similar material of undetermined extent, about 5 kilometers southeast of Jabal 'An. It is also exposed in the pediment about 1 kilometer to the north-northeast of Jabal Sak. To the southwest of Jabal 'An, in the vicinity of sample 42118, much scattered magnetite float, which has as yet not been followed up, points to other iron sources. Goldsmith([illegible]) has also reported on some hematite veins, up to 9 meters wide, located to the north and west of Mamilah. Iron resources, then, would seem to be adequate for a cement plant operation.

GYPSUM

A small amount of ground gypsum is generally added to the cement either separately at the point of use or ground with the cement clinker. Gypsum was not encountered during this investigation. Small exposures of gypsiferous material would, in any event, be easily eroded and covered by the veneer of the pediment. However, the presence of dolomite suggests that contemporaneous gypsum might be found in some parts of the same sedimentary basin. Failing this, the small amount of gypsum needed could be brought in from deposits along the Red Sea coast.

BUILDING MATERIALS

Medium- to thick-bedded dolomite in colors of yellowish-brown, purple, white, and gray has been located about 10 kilometers north of Jabal Sak. Some of it is finely porous, but it is strong and takes an excellent polish. It does not discolor on weathering and can be easily worked and quarried. It would seem to be quite suitable as a decorative building stone. Similar stone is presently being brought from Jabal Tuwayq near Riyadh and used for decorative facings on buildings in Taif.

A coarse-grained, buff-weathering, white, magnesian marble is presently being quarried sporadically for flagstone from a pendant of intensely folded Precambrian carbonate rock located about 25 kilometers southwest of Jabal 'An. Because of its close jointing and discoloration on weathering, this rock is not suitable for building purposes. Goldsmith (in press) also mentions several marble localities: one, near the head of Wadi Durah lying a few kilometers to the south of the new Taif - Bishah highway about 80 kilometers southeast of Taif; another at Wadi Jufayr located about 15 kilometers southwest of Turabah.

Gray, fine-grained granite is presently being quarried in a desultory way near the eastern outskirts of Taif. A more distinctive granite could, no doubt, be located in the area should the need arise.

The importance of sand and gravel to a growing community is generally little noted until the need becomes critical. In the developing Taif area the availability of this material is of increasing concern. The wadis draining into the Al Jarad from the southwest carry abundant sand but a disproportionately small amount of coarse gravel. This source of aggregate is therefore limited, and present needs are being met by quarried crushed stone. While quarried stone aggregate is satisfactory for some purposes - mainly for roads and foundations - the sounder aggregate produced from crushed, stream-battered cobbles is preferred for buildings. Because of the importance of aggregate for the development of the area, a more systematic investigation of possible sources might well be undertaken.

A source of light-weight aggregate would be of particular value to the construction industry. Indurated tuff-stone and pumicite are widely used for this purpose. The lower section of the volcanic sequence of Harrat Hadan is made up, in part, of bedded tuffs. The suitability of this material, as well as of other pyroclastic rocks in the area, as a light-weight aggregate should be tested. Expansible shales are also used for this purpose. Shale localities of this nature in the area investigated remains to be established, but the possibility should not be discounted.

A more recent development has been the manufacture of aggregate specifically for concrete blocks and other applications where light weight is a consideration. A small amount of crude oil is mixed with impure clay, rolled out into ribbons, cut into suitably sized pellets, and fired in a rotary kiln. The product resembles scoria. It makes a light but strong aggregate.

BENTONITE

As mentioned above, the lower section of the Tertiary volcanic sequence of Harrat Hadad consists in part of tuffs. In most places the volcanics overlie Tertiary carbonate rocks, but there is also some intercalation of tuff and basalt in the upper part of the carbonate sequence. This enhances the prospect that in some parts of the basin the tuff may be altered to bentonite. The magnesia content of the clay represented by analyses 42127, 42129, and 42130 suggests such a transformation. The low soda content would indicate it to be of the non-swelling variety. As "activated" clay, low-soda bentonite finds a wide variety of uses in industry, particularly in oil refining.

CONCLUSIONS

Limestone, clay, siltstone, argillite, quartz pebble conglomerate, and pisolitic iron ore exist in adequate volume within a radius of 90 kilometers to the east and northeast of Taif to support a cement plant operation should the establishment of such an enterprise prove economically feasible. Gypsum has not as yet been found in the area and the small amount usually required would have to be brought from elsewhere There is, however, some likelihood that gypsum may be encountered locally in the subsurface.

Building materials, such as marble and granite are being quarried sporadically in a small way for limited local use. When the Taif-Bishah highway, now under construction, is sufficiently advanced to make some of the outlying marble outcrops more readily accessible, a detailed investigation of these resources should be undertaken. Some of the variously colored dolomite cropping out a few kilometers north of Jabal Sak, might make a suitable decorative building stone.

As the Taif area develops, the need for sound, coarse concrete aggregate will become more pressing. Naturally occuring sources are limited and even these remain to be developed. Quarried crushed rock is one answer to this need. Crushed cobbles from the base of the scarp lying to the west of Taif is another. Indurated volcanic ash, expansible shale and natural or manufactured scoria for use as aggregate in concrete blocks and other light-weight construction might be developed in the area. These possibilities have yet to be explored.

A further prospect is the possibility of uncovering deposits of bentonitic clays in the area lying directly to the west of the Harrat Hadan. A more definite answer, however, waits upon a more detailed investigation.

RECOMMENDATIONS

The rapid growth of the Taif area as a recreational, governmental, and communications center will require, sooner or later, an inventory of the resources of the surrounding region so that these may be developed in an orderly manner to support this growth for the benefit of the country as well as for the benefit of the local inhabitants. While the following recommendations have in mind primarily the needs of the construction industry they should be viewed as touching upon only one aspect of what could become a more inclusive development program involving agriculture, water resources, the utilitarian needs of the municipality, and the exploitation of the recreational potential. The recommendations listed below are extended to include some of these wider considerations.

1. Topographic and geologic maps are an indispensible part of the framework to which all other data are referred. Mapping is therefore important not only in the initial phases of any development program but also as a continuing concern.

First in order, then, is detailed geologic mapping at a scale of 1:50,000 beginning with the area of carbonate rocks, which are of immediate interest, but ultimately covering the entire quadrangles in which they lie. This work would be done in any event as part of the general mapping program covering the Arabian Shield.

2. Detailed sampling and description of the outcrops of possible cement raw materials. This might include running some shallow seismic traverses and test pitting for clay and siltstone.

3. Topographic and detailed geologic mapping of the more promising sites at a scale of 1:10,000.

4. Drilling 4 or 5 large, shallow bore holes on some sites for stratigraphic, chemical, and hydrologic information.

5. Up to this stage the exploration would be general. Before the actual raw material development phase is undertaken a feasibility study should be made.

6. On the affirmative outcome of the feasibility study, supplementary, closer-spaced drilling should be undertaken in the areas finally selected as possible quarry sites.

7. Mapping of the possible quarry sites at a scale of 1:1000 for pit design, the planning of quarrying operations, and for quality control of raw materials.

8. Development of one or two test quarries.

9. Stockpiling of raw materials.

10. Concurrently with the foregoing, or independently, the occurrence of bentonite and other clay deposits might be investigated.

11. A search for light-weight aggregate, and an evaluation of the availability of dense aggregate might be made.

12. The investigation of marble, granite, decorative stone, and other building materials might well be included.

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