4.2 THE NORTH HILL

The location of the geoelectrical survey lines for the North Hill are shown in Fig. 26. Also shown are the geoelectrical resistivity cross sections for line 7 (200 m, southern side of the hill), and line 8 (100 m, northern side of the hill). The larger scale geoelectrical resistivity cross sections for the lines are shown in Fig. 27 (line 7) and Fig. 28 (line 8).

For the North Hill, three boreholes were excavated, BH-4, BH-5 and BH-6. Two geoelectrical resistivity lines were conducted at this location. Line 7 is located at the southern part of this hill, trending WNW-ESE on the west portion and ENE-WSW on the east portion. The line can be correlated with borehole BH-5 and BH-6. Line 8 is located along the northern face of the North Hill and can be correlated with borehole BH-4. Both these lines indicate that the subsurface conditions as determined by the geoelectrical resistivity imaging is relatively uniform. The top layer with relatively low resistivity (< 100 Ωm) represents the overburden, which is sandy silt with some quartz pebbles. Below this overburden layer, the geoelectrical resistivity values increase progressively with depth, indicating the presence of limestone with a decreasing degree of fracturing with depth. Although in both borehole BH-5 and BH-6 cavities were detected, the geoelectrical resistivity imaging does not show the presence of cavities at the surveyed locations, suggesting that these cavities have limited lateral extent. The results also indicate that the detectibility of subsurface cavities decreases with increasing depth.

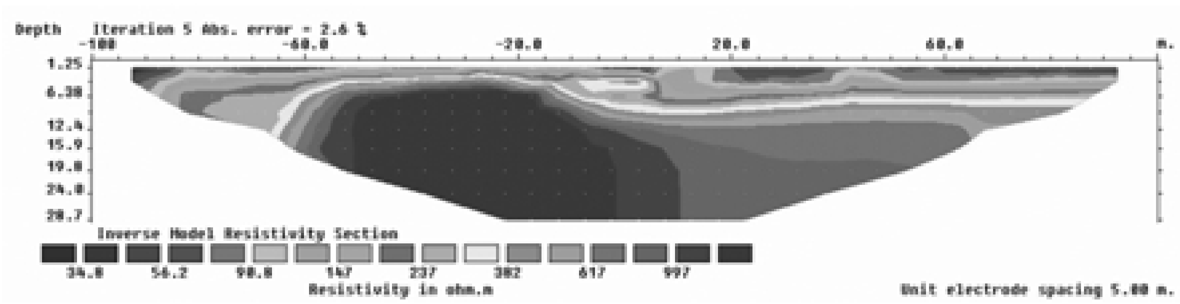

Fig. 27: The geoelectrical resistivity cross section of line 7 of the North Hill.

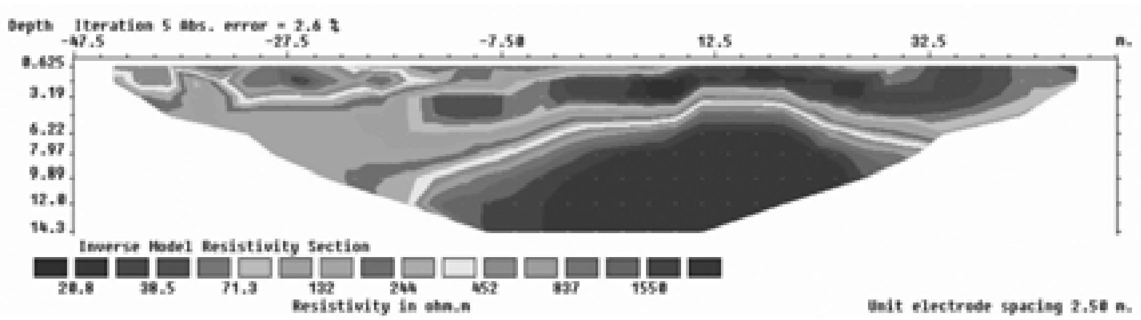

Fig. 28: The geoelectrical resistivity cross section of line 8 of the North Hill.

5 MINERALOGICAL AND CHEMICAL COMPOSITION

5.1 MINERALOGICAL COMPOSITION

The mineralogical compositions of selected samples, both from above-surface and underground, were determined by petrographic technique, supplemented by X-ray diffraction technique (XRD). A total of 22 samples were selected, comprising 10 above-surface and 12 underground samples from boreholes. Five of the 10 above-surface samples were selected amongst 10 samples collected for chemical analysis from the South Hill and the remaining five were selected amongst 12 samples collected from the North Hill (refer Table 2 and Table 3 for their GPS coordinates and height, respectively). Two samples were selected from each borehole, making the total of 12 samples. The summary of samples used for the mineralogical study is shown in Table 7 below.

Table 7: The summary of samples for mineralogical study.

	No.	Sample from South Hill	No.	Sample from North Hill
Above Ground Samples	1	59B	6	81B
	2	61B	7	83A
	3	77A	8	83B
	4	77C	9	89A
	5	80	10	91
Below Ground Samples	11	BH-1 9.50 M	17	BH-4 15.0 M
	12	BH-1 24.5 M	18	BH-4 33.0 M
	13	BH-2 10.5 M	19	BH-5 9.50 M
	14	BH-2 31.5 M	20	BH-5 24.5 M
	15	BH-3 22.5 M	21	BH-6 10.0 M
	16	BH-3 40.5 M	22	BH-6 22.0 M

5.1.1 **Petrography**

5.1.1a ***Macroscopic Study***

The observation made on hand specimens has enabled the subdivision of the rock into two types: (1) fine to medium-grained crystalline dolomite, dark grey in colour, and (2) medium to coarse-grained crystalline dolomite, grey in colour with abundant cross-cutting veins of calcite.

The fine to medium-grained dolomite is the most common and abundant rock type, which exposes in both the South Hill and the North Hill. This type of rock accounts for approximately 90% of the dolomite as a whole. Apart from being dark grey in colour, the rock are massive and compact, less fractured and cross cutting calcite veins are not common. However at certain localities, foliation or lamination structures can be observed (Fig. 29).

The second type of rock is not wide spread in distribution; these rock expose at certain localities in the South Hill and were also observed in the borehole samples at certain depth. Out of 22 samples studied, only 4 samples belong to this type. It is believed that the rock occur through recrystallisation of the original dolomite due to deformation and intrusion of nearby magmatic body. Undoubtedly, the occurrence of the rock is somewhat controlled by the structure, as they are commonly connected with joints and fractures which occurred during the deformation of the rock. Almost all joints and fractures were filled up by calcite veins (Fig. 30). Table 8 below shows the hand specimen description of the 22 samples.

Table 8: The macroscopic nature of dolomite samples.

No	Sample No.	Hand Specimen Description
1	59B	Dark grey, fine to medium-grained, massive and compact, no fracture observed.
2	61B	Dark grey, fine to medium-grained, massive and compact, no fracture observed.
3	77A	Dark grey, fine to medium-grained, massive and compact, no fracture observed.
4	77C	Dull grey, medium to coarse-grained, massive, calcite filling fractures.
5	80	Dark grey, fine to medium-grained, massive and compact, no fracture observed.
6	BH-1 9.50 M	Dark grey, fine to medium-grained, massive and compact, no fracture observed.
7	BH-1 24.5 M	Dark grey, fine to medium-grained, massive and compact, no fracture observed.
8	BH-2 10.5 M	Dull grey, medium to coarse-grained, massive, calcite filling fractures.
9	BH-2 31.5 M	Dark grey, fine to medium-grained, massive and compact, no fracture observed.
10	BH-3 22.5 M	Dull grey, medium to coarse-grained, massive, calcite filling fractures.
11	BH-3 40.5 M	Dark grey, fine to medium-grained, massive and compact, no fracture observed.
12	81B	Dark grey, fine to medium-grained, massive and compact, no fracture observed. Laminated.
13	83A	Dark grey, fine to medium-grained, massive and compact, no fracture observed.
14	83B	Dark grey, fine to medium-grained, massive and compact, no fracture observed.
15	89A	Dark grey, fine to medium-grained, massive and compact, no fracture observed.
16	91	Dark grey, fine to medium-grained, massive and compact, slightly fractured.
17	BH-4 15.0 M	Dark grey, fine to medium-grained, massive and compact, slightly fractured.
18	BH-4 33.0 M	Dark grey, fine to medium-grained, massive and compact, no fracture observed.
19	BH-5 9.50 M	Dull grey, medium to coarse-grained, massive, calcite filling fractures.
20	BH-5 24.5 M	Dark grey, fine to medium-grained, massive and compact, no fracture observed.
21	BH-6 10.0 M	Dark grey, fine to medium-grained, massive and compact, highly fractured.
22	BH-6 22.0 M	Dark grey, fine to medium-grained, massive and compact, slightly fractured.

5.1.1b ***Microscopic Study***

Sample preparation

The rock sample was cut and sliced into a slab, 2 cm x 4 cm x 0.5 cm using diamond blade rock saw machine (Fig. 31). One side of the slab was mounted onto a grinder, containing wheel which grinds the slab while rotating (Fig. 32). The ground surface was further smoothened and flattened by hand grinding on a piece of glass with fine grain powder of silicon carbide, lubricated with water. After cleaning with ultrasonic cleaner the slab was heated on a hot plate for about one hour. The smooth and flat surface was bonded to a standard glass slide using Canada Balsam (a type of resin) (Fig. 33).

After gradual cooling, the exposed surface was trimmed down to approximately 40 microns in thickness by using a trimming machine (Fig. 34). The exposed surface was grounded again using finer silicon carbide powder until a thickness of 0.03 mm (30 microns) was achieved. After cleaning, the exposed surface was covered with a thin glass slide cover to avoid contamination or damage to the sample (Fig. 35).

Microscope Observation

Carl Zeiss polarizing research microscope was used. Sibley and Gregg classification of dolomite rock is adopted.

Fig. 29: The dolomite Type One which is dark grey in colour, of fine to medium-grained size. The lineation of mineral observed in the sample.

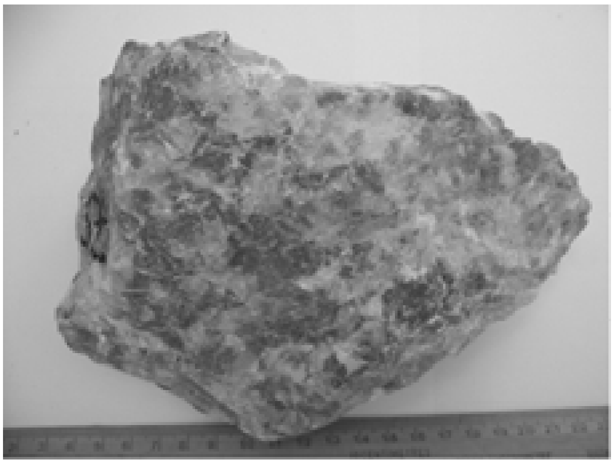

Fig. 30: The dolomite Type Two consists of abundant of calcite veins (white colour). It is dull grey in colour of medium to coarse-grained size and is slightly fractured.

Fig. 31: The diamond blade rock saw machine.

Fig. 32: The grinder with the rotated wheel used to grind the slab of rock.

Fig. 33: The sample on the hot plate before the glass slide is being lapped into.

Fig. 34: The trimming machine

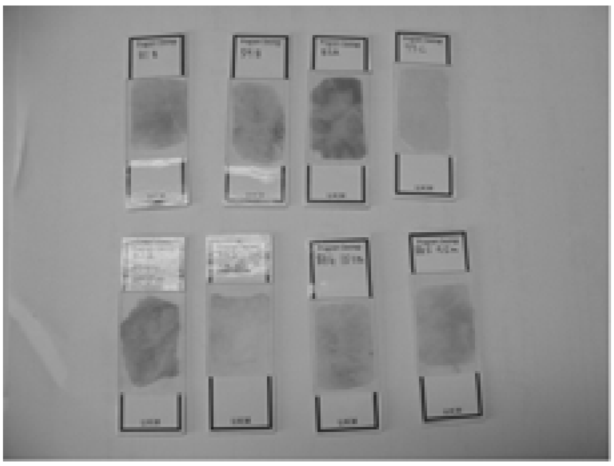

Fig. 35: The thin section of the dolomite samples. It shows eight samples from 22 samples prepared and examined through a microscope.

Fine to medium-grained crystalline dolomite

The rock are fine to medium-grained (0.1 mm to 0.5 mm), consisting of two minerals: (1) dolomite, and (2) calcite. Dolomite is far more abundant than calcite. Table 9 shows the result of point counting performed on the thin sections of the samples. The average percentage of dolomite is 98.41%; calcite occurs in small amount (average of 1.58%). Under the microscope, dolomite occurs as euhedral (good shape) aggregates of grains, tightly compacted together. The minerals are dark to dark brown in colour as compared to calcite, which is yellow to brownish yellow (Fig. 36). The brown to dark brown colour suggests that they are rich in magnesium (Fig. 37, Fig. 38). Some of the samples are medium-grained, but dolomite is still the most abundant mineral although the amount of calcite increases, some of the calcite occur as veins (Fig. 39).

Table 9: The percentages of dolomite and calcite in fine to medium-grained rock.

No	**Sample No.**	**% Dolomite**	**% Calcite**
1	59B	97.78	2.22
2	61B	97.65	2.35
3	77A	98.22	1.78
4	80	97.68	2.32
5	BH-1 9.50 M	97.72	2.28
6	BH-1 24.5 M	98.76	1.24
7	BH-2 31.5 M	98.87	1.13
8	BH-3 40.5 M	98.52	1.48
9	81B	98.74	1.26
10	83A	98.92	1.08
11	83B	97.86	2.14
12	89A	99.38	0.62
13	91	98.88	1.12
14	BH-4 15.0 M	98.45	1.55
15	BH-4 33.0 M	98.56	1.44
16	BH-5 24.5 M	98.35	1.65
17	BH-6 10.0 M	98.02	1.98
18	BH-6 22.0 M	99.04	0.96
	Average	**98.41**	**1.58**

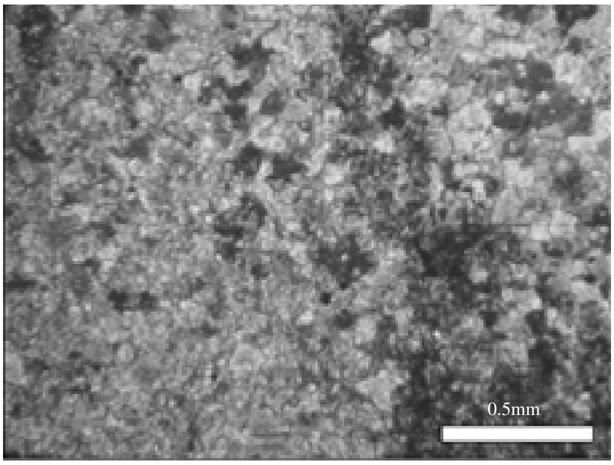

Fig. 36: Microscopic features of a fine to medium grained dolomite sample. It shows the distribution of dolomite mineral with a dark to dark brown colour.

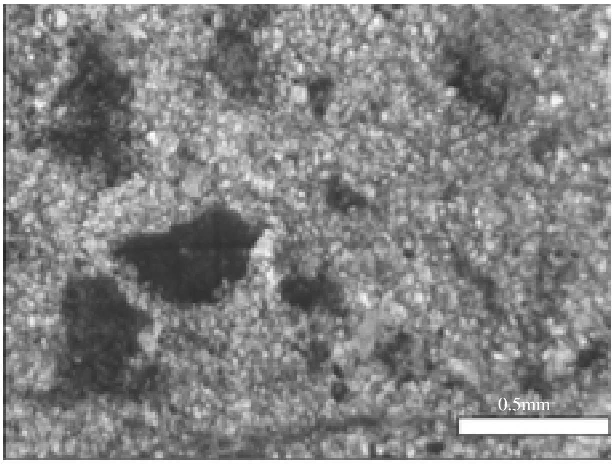

Fig. 37: The dark brown of dolomite mineral which is high content magnesium occurred as a nodule in the sample.

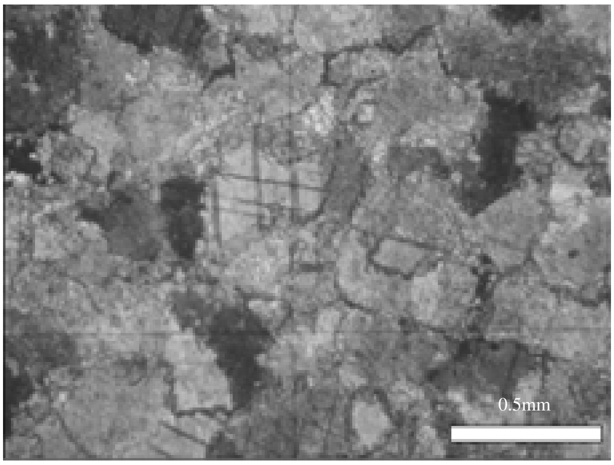

Fig. 38: Microscopic features of a medium-grained size of dolomite. The size of mineral observed is between 0.1 mm to 0.5 mm in length.

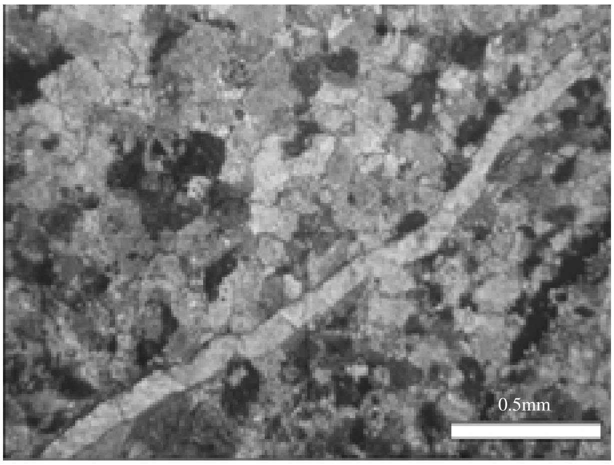

Fig. 39: Microscopic features of a medium-grained size of dolomite. The small calcite vein is cross cutting the rock.

Medium to course-grained crystalline dolomite

This type of rock shows grain size ranging between 0.5 mm and 1 mm (Fig. 40). Calcite can be recognized by the cleavage (Fig. 41). Point counting has shown that the average percentages of dolomite and calcite in four samples are 97.63% and 2.37% (please see Table 10), respectively. In general, this type of rock contains a higher amount of calcite as compared to the fine-grained variety but mainly occurs in fractures and micro veins.

Table 10: The percentages of dolomite and calcite in medium to coarse-grained rock.

No.	Sample No.	% Dolomite	% Calcite
1	77C	97.04	2.96
2	BH-2 10.5 M	97.05	2.95
3	BH-3 22.5 M	98.45	1.55
4	BH-5 9.50 M	97.98	2.02
	Average	**97.63**	**2.37**

5.1.2 X-ray Diffraction Technique

X-ray diffraction (XRD) is an instrumental technique capable of identifying phases (compounds), as long as the phases occur in crystalline form. Crystalline phases, minerals included, are made of crystals with a unique internal atomic arrangement. Each phase in a crystal has its unique and constant d-spacing, i.e. a distance measured in Angstrom between repeating layers of similar atomic arrangement. It is the d-spacing of a crystal which differentiates it from others.

5.1.2a ***Determination of Mineral Content***

The Theory

By bombarding a crystalline sample with an X-ray (widely used is CuK-α), the sample produces a unique XRD pattern, comprising peaks, each one belonging to a crystal phase with a unique d-spacing. The pattern is matched with those of other known materials, called standards (popularly known as JCPDS standard), which are stored in the computer systems (about 100,000 patterns of known materials are kept in D-5000 Siemens Diffractometer). The name of an unknown phase is assigned when its pattern matches a specific standard.

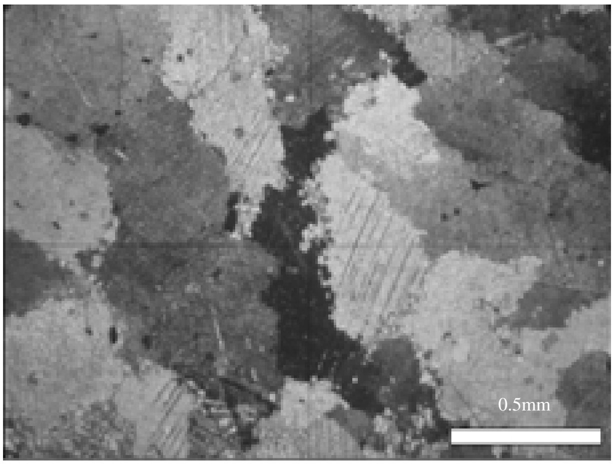

Fig. 40: The microscopic features of the dolomite type two.

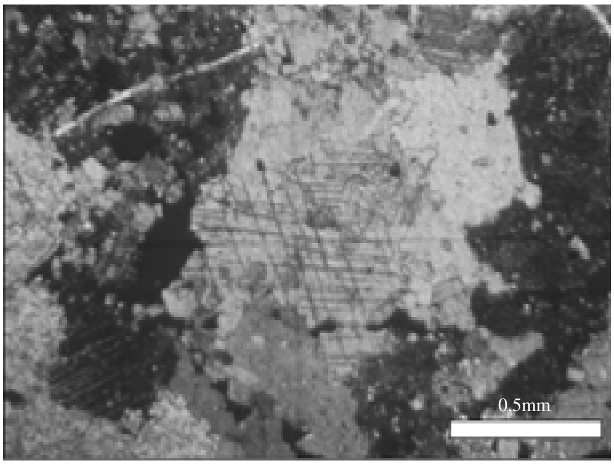

Fig 41: Microscopic features of a coarse grained dolomite. It shows the calcite mineral which is recognized by the cleavage.

Normally, the three strongest peaks are sufficient to identify a crystalline phase. However, a higher degree of confidence will be achieved if more than three peaks are available. For example, dolomite is positively identified if we can see the strongest peak (with *d-spacing* of 2.89Å), the second strongest peak (with *d-spacing* of 2.19Å) and the third strongest peak (with *d-spacing* of 1.79Å) (JCPDS File No. 11-078). By the same method we can say that calcite is absent in the sample if the pattern does not show peaks with *d-spacing* of 3.04Å. 2.29Å and 2.10Å, i.e. the three strongest peaks for the mineral (JCPDS File No. 5-586).

The X-ray diffraction patterns for the samples have been produced using a fully-automated Siemens D-5000 Diffractometer, equipped with DIFFRAC-XT software (Fig. 42), with the following operational condition:

Source of radiation	:	Cu K-α, λ = 1.5418 Å.
KV	:	40
mA	:	30
Step scan speed	:	0.04°2Θ / second, or 2.4° 2Θ / minute
Scan range	:	2 - 60°.

A standard laboratory procedure was used to transform the surface samples and the borehole samples into a fine powder (individual grains are 20 to 30 microns in size). The pulverizing process involves cleaning and drying of the sample, crushing the sample into 1 cm to 2 cm fragments using a jaw crusher and grinding the fragments into powder using a silicon carbide-coated milling cup. The pulverized samples are stored in air-tight, labeled plastic bottles (Fig. 43).

For XRD analysis, the specimen is in the form of an untreated, dry sample powder in circular hole on a flat sample holder, hand-pressed to get a flat surface (Fig. 44).

The Result

A total number of 22 samples have been studied. The samples comprised of 10 surface samples (5 each from the South and the North Hill) and 12 below surface samples, i.e. 2 each from borehole BH-1, BH-2 and BH-3 (South Hill) and borehole BH-4, BH-5 and BH-6 (North Hill).

The XRD patterns produced have proven that all the samples analysed are made up of dolomite as the major mineral, with minor to trace amount of calcite. Table 11 contains a summary of the findings and the individual XRD pattern for the samples is shown in Fig. 45 to Fig. 66.

Fig. 42: Siemens D-5000 Diffractometer for the XRD analysis.

Fig. 43: The Pulverised sample.

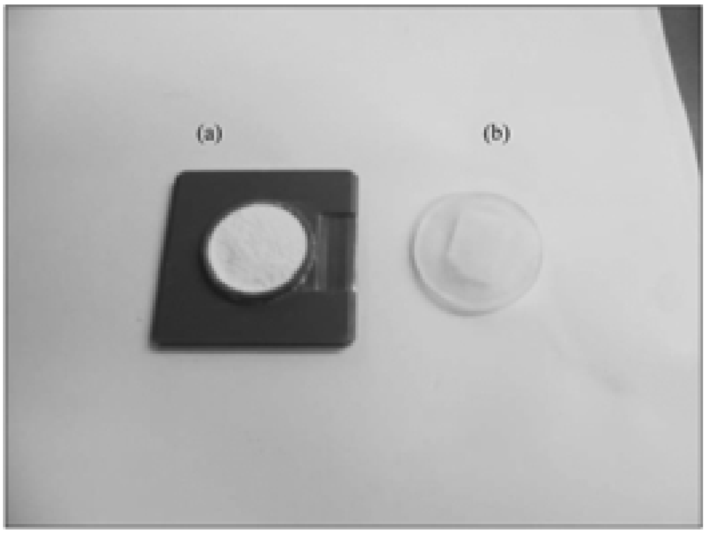

Fig. 44: Two types of sample preparation 1, (a) for XRD analysis and (b) for XRF analysis.

Table 11: The Summary of Mineral Content in 22 Samples by XRD.

Place (Hill)	Sample No.	Mineral Content	Fig. No.
South Hill (Surface)	59B	Dolomite >> Calcite	Fig. 45
	61B	Dolomite >> Calcite	Fig. 46
	77A	Dolomite >>> Calcite	Fig. 47
	77C	Dolomite >> Calcite	Fig. 48
	80	Dolomite >> Calcite	Fig. 49
South Hill (Boreholes)	BH-1 9.5M	Dolomite	Fig. 50
	BH-1 24.5M	Dolomite >>> Calcite	Fig. 51
	BH-2 10.5M	Dolomite	Fig. 52
	BH-2 31.5M	Dolomite	Fig. 53
	BH-3 22.5M	Dolomite > Calcite	Fig. 54
	BH-3 40.5M	Dolomite >> Calcite	Fig. 55
North Hill (Surface)	81B	Dolomite >>> Calcite	Fig. 56
	83A	Dolomite >>> Calcite	Fig. 57
	83B	Dolomite >>> Calcite	Fig. 58
	89A	Dolomite	Fig. 59
	91	Dolomite >>> Calcite	Fig. 60
North Hill (Boreholes)	BH-4 15.0M	Dolomite >> Calcite	Fig. 61
	BH-4 33.0M	Dolomite >> Calcite	Fig. 62
	BH-5 9.5M	Dolomite >>> Calcite	Fig. 63
	BH-5 24.5M	Dolomite	Fig. 64
	BH-6 10.0M	Dolomite >>> Calcite	Fig. 65
	BH-6 22.0M	Dolomite >> Calcite	Fig. 66