DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Description, Selection, And Procurement Of Shelburne Marble Samples Used To Study Effects Of Acid Rain

by

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INTRODUCTION

As part of the National Acid Precipitation Assessment Program (NAPAP), the research goal of the Materials Effects Task Group (G) is to assess the damage caused by acid deposition on selected building materials, including dimension stone[1/]. One of the ways this damage is being assessed is by exposing dimension stone at various outdoor sites where acid depositon and other environmental parameters are being measured continuously. The change in properties of the exposed stone as compared to the unexposed stone is measured and analyzed.

The previous report of this series (Ross and Knab, 1984) describes the first stone selected for field exposure studies, the Salem Limestone from Bloomington, Indiana. This report describes the second stone selected for this program, the Shelburne Marble from Danby, Vermont. This particular marble was chosen because: (1) it has widespread use in the United States, (2) it is susceptible to dissolution and deterioriation in the general outdoor environment, particularly when exposed to acid conditions, (3) it commonly contains a polish, and (4) it is readily available from a quarry that has furnished stone to major building projects for many years; especially those in the northeastern United States where rain is particularly acidic.

1/ Dimension stone refers to stone precut to specific sizes and shapes.

THE VERMONT MARBLES

In a geologically strict sense, marble is a metamorphic rock, the precursor carbonate-rich sediment having recrystallized under elevated temperature and pressure to predominantly fine-to coarse-grained calcite ($CaCO_3$) and/or dolomite ($CaMg(CO_3)_2$). In commerce, marble is a term applied to any more or less crystallized limestone capable of taking a polish. Some stone is referred to as marble which contains little or no carbonate material; for example, verde antique "marble" from Rochester, Vermont which is actually a metamorphosed serpentinite composed mostly of serpentine ($Mg_3Si_2O_5(OH_4)$) and containing only a small amount of calcite. Most of the "marble" quarried in Vermont is metamorphosed carbonate-rich rock.

For most of this century, Vermont has been the leader in marble dimension stone production, but as of 1980 Vermont and Georgia each produced about 30 percent of the United States output (Singleton, 1981). Notable buildings constructed with Vermont marble are the New York City Library, the Philadelphia Federal Reserve Bank, and in Washington, D.C., the Red Cross Building, the Memorial Continental Hall of the Daughters of the American Revolution, the Jefferson Memorial, the Supreme Court and the Rayburn Buildings, and the new French Embassy.

Color of the Vermont Marbles

The marbles of Vermont show a wide range of color hues reflecting variations in the amount and types of mineral inclusions within the calcite or dolomite matrix. The black or gray marbles owe their shade to the presence of carbon, usually in the form of graphite disseminated throughout the calcite or dolomite crystals. Carbonaceous material causes the dark coloring in the unmetamorphosed marbles quarried in the northern part of the Vermont marble belt; examples are the marbles from Isle La Motte. The reddish-brown marbles contain small inclusions of iron or manganese oxides; the green-tinted marbles owe their color partly to silicate inclusions, particularly chlorite or actinolite, and the yellow to brown marbles contain inclusions of muscovite, phlogopite, and pyrite. Often the mineral inclusions are concentrated into patches or streaks within the usually white matrix which gives a characteristic mottled appearance to the stone surface and lends an individuality to each particular marble. The beauty or quality of the distinctive stone surfaces led to the use of special names to designate the marbles, for example, Ruvano, Champlain, Jasper, etc. Perkins (1933, p. 175-205) gives descriptions of 102 different Shelburne marbles (see also Dale, 1912, p. 150-154).

Geological Setting

The marble belt of western Vermont is included within a sequence of carbonate-rich rocks that extends from the Canadian border north of Swanton, Vermont nearly due south to southern Vermont (Fig. 1). The northern part of this carbonate sequence, located between the towns of Swanton and Milton and including the Isle La Motte and Grande Isle areas, is composed of unmetamorphosed calcites and dolomites. Stone quarried in this northern area are referred to as the "Lake Champlain Marbles." These are often quartzose dolomites of mottled to uniform pink, purplish and gray color. "Marbles" from Isle La Motte (Fisk black, Fisk gray) are composed mostly of calcite, contain little dolomite but much carbonaceous material to give the dark color, and are highly fossiliferous.

The true marbles of western Vermont are included within the Shelburne Formation, a belt of metamorphosed carbonate-rich sediments extending from Shelburne 85 miles south to Manchester. The northern portion of this marble belt, located between the towns of Shelburne and Middlebury, is characterized by extremely fine-textured rock that occurs in open folds lying between thrust falts. The southern portion of the marble belt, the area that has produced the most marble, extends from Middlebury to Manchester. These latter marbles are medium to coarse-grained in texture and often form complex folded structures.

Past Centers of Marble Quarrying in Vermont

Dale (1912, 1914), Perkins (1914, 1933), and Bain (1934) give detailed accounts of the geology of the Vermont marble deposits as well as the history of the marble quarring operations in Vermont from the time they started in the late 18th century up until the early part of the 20th century; years in which the industry began and matured.

In the past, as many as 50 quarries were operating from Swanton and Isle La Motte near the Canadian border to Manchester in the south. Main centers of quarrying were near the towns of Manchester, Dorset, Danby, Clarendon, Rutland, Proctor, Pittsford, and Brandon. The quarries of the Manchester-Dorset area produced much of the marble used in New York City. Quarries just to the north in the West Rutland Valley produced the famous West Rutland blue marble as well as white marble. The Pittsford area produced Sutherland Falls marble, Columbia marble, and the very durable blue-gray marble known as Florentine. The Brandon Italian Quarry produced a light blue-gray stone composed of calcite marble crossed by small dark-gray graphitic dolomite beds.

The quarries located north of the Brandon area were less productive than those to the south, however, some notable marbles were quarried in this area; the Monkton Quarry produced a mottled pink and white quartz and hematite-bearing dolomite known as the Ruvaro marble, the Swanton quarries produced the Champlain, Royal Red, Jasper, Lyonnaise, Oriental,

and Olive dolomite marbles, and the Fisk Quarry on Isle La Motte produced Fisk black and Fisk gray; unmetamorphosed calcite marbles containing abundant fossils, carbon, and small amounts of dolomite.

In August of 1983 the author spent 10 days visiting the old (now mostly abandoned) Vermont marble quarries. These included: the Freedley Quarry located on the flank of Dorset Mountain west of Freedleyville (this quarry was opened in 1790 but is now flooded), the active Danby Quarry, and abandoned quarries in West Rutland, Proctor, Florence, Pittsford, Brandon, and Middlebury. Samples of marble were collected from the several quarries as reference materials to compare to similar stone now in place in buildings throughout the eastern United States.

THE DORSET PEAK QUARRIES

Historical

The Danby area of Vermont is notable for its productive marble quarries located on the north and northeast sides of Dorset Peak, the summit of which lies 2.8 miles (4.5 km.) SSW of the town of Danby. In this area, the marble belt lies higher up on the mountainside (~1600-2000 feet elevation) and here it is also much folded and in places faulted. Dorset Peak is deeply furrowed by erosion and the marble is naturally exposed on its three sides. The Dorset Peak quarries first opened in 1840 and in just a few years seven cutting mills were operating. The two most productive quarries on Dorset Peak were the old Imperial and New York Quarries. The Imperial Quarry, located 1.5 miles (2.4 km.) SSW of Danby, opened in 1900. Here the marble beds are 4 to 8 feet thick separated by very thin sheets of mica schist. One of the important marbles shipped from the Imperial Quarry was known as Danby.

The old New York Quarry, opened in the early 1900's, is located approximately 0.2 miles (0.3 km.) WNW of the Imperial Quarry. The marbles here are not essentially different from those of the Imperial Quarry (see Dale, 1912, p. 108-110, Plate I).

The Danby Quarry

The only marble dimension stone quarry now operating in Vermont is the Danby Quarry[2/] owned by the Vermont Marble Company, Proctor, Vermont. This underground quarry is located 1.6 miles (2.6 km) due south of the

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2/ This quarry is variously referred to as: the Danby Quarry, the Imperial Quarry at Danby, and the Danby Imperial Quarry. For the purposes of this paper this quarry is referred to as the Danby Quarry.

Danby (43° 19.3'N - 73° 0.2'W, U.S. Geological Survey 7.5 Minute Series, Dorset Quadrangle, Vermont, 1967). The Danby Quarry is situated approximately 0.3 miles east (0.5 km.) of the old Imperial Quarry described above.

The marble beds or layers at the Danby Quarry show a considerable variation from one horizon to another in color and kinds and amounts of mineral inclusions. The layering of the marble formation reflects the original sedimentary structure which persisted through metamorphism although the layers are often folded by later arising tectonic forces. Within each layer the marbles generally have similar chemical and mineral compositions, thus the stone from a particular layer will usually have very similar color and textural properties.

As with other quarries, the marbles from the individual layers are given special names that relate to their characteristic color patterns. The layer designations and general stratigraphic relationships of the Danby Quarry marbles are shown diagramatically in Figure 2. The commercial marble from these various layers and sub-layers are called Royal, Imperial, Montclair, Mariposa, Plateau-Dark, Pearl, Corona, and Highland (Fig. 2). The Royal and Imperial are two commonly used dimension stone marbles.

According to the descriptions of Dale (1912), some of the marbles from the old Imperial and New York Quarries appear to be similar to the Royal and Imperial of the Danby Quarry. Dale (1912, p. 108-110) describes the Danby marble from the old Imperial Quarry as "a coarse calcite marble of faintly cream-tinted, somewhat translucent color with yellow-greenish-gray irregular streaks or mottlings...." Stone from these quarries containing streaks of mineral inclusions that were predominantly yellow or champagne in color probably corresponds to the Imperial stone from Danby; the more greenish- or bluish-gray streaked marble probably corresponds to the Royal from Danby. The yellow streaking is due to inclusions of muscovite, phlogopite, and pyrite. The greenish- or bluish-gray streaking is caused by inclusions of chlorite, phlogopite, dolomite, and perhaps carbon.

SELECTION AND CUTTING OF ROYAL MARBLE

Selection

After consideration of the historic use of various marbles in buildings within the United States, site visits to the important Vermont marble deposits, both past and present, and consulting with officials of the Vermont Marble Company, it was decided that the most suitable marble for the material affects study by Task Group G (NAPAP) would be the Royal marble from the C-layer of the Danby Quarry. A return trip was made to Vermont in December, 1983, in order to photograph the positions from which the study blocks were quarried and to supervise the cutting of the block and the labeling of the cut pieces.

Cutting

Two marble blocks were cut from the C-layer (1141 foot level, Grid H-23) of the Danby Quarry. Figure 3 shows a portion of the Danby mine map indicating exact locations of quarry blocks I and II. After sawing, block I was found to be defective and the second block (II, quarry no. 83DC, 2528) measuring 3.5 x 6.5 x 6.5 feet in size was sawn into one 4-inch and 14 2-inch slabs. Block II, which is shown in Figure 4 proved to be sound.

The 15 slabs were then cut in 252 pieces measuring 2x12x24 inches in size and into 18 pieces measuring 4x12x24[3/] inches in size. One large face of each piece was then polished to an 80 grit finish - a finish that is often furnished on Vermont marble dimension stone. The labeling scheme for the individual 2-inch and 4-inch thick pieces is shown in Figure 5.

The cut and polished pieces were trucked to the National Bureau of Standards in Gaithersburg, Maryland where they were stored indoors at or near room temperature. Here, some of the 2-inch thick pieces were further cut into briquetts measuring 3 inches wide, 3 5/8 inches long, and 2 inches high. To aid in securing the briquetts to the test racks, two edges were beveled as shown in Figure 6.

The stone is presently stored at the Argonne National Laboratory, 9700 South Cass Avenue, Building 212, Argonne, Illinois 60439. Mr. Arthur Youngdahl is the curator.

3/ The 4-inch thick pieces are necessary for physical and mechanical tests requiring thicknesses in excess of 2 inches.

ACKNOWLEDGMENTS

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FIGURE CAPTIONS

Figure 1. Index map of Vermont.

Figure 2. Vertical cross-sectional representation of the marble layering found in the Danby Quarry, Danby, Vermont. Different layers often have distinctive color and texture and thus are given special names such as Royal, Imperial, Pearl, etc. The layering is not always horizontal and individual layers sometimes pinch out and disapper (Figure furnished by the Vermont Marble Company).

Figure 3. Portion of the underground mine map of the southern end of the Danby Quarry. Scale: 1 inch = 20 feet. Pillars of unextracted marble are shown as stippled areas. Elevations above sea level are shown at each corner of a pillar. The sites of the extracted blocks of test stone (I, II) are shown within location H-23, elevation is 1141 feet (map furnished by the Vermont Marble Company).

Figure 4. Photograph of marble test block II; top; of the block is to the right, south side of the block faces viewer.

Figure 5. Labeling scheme used to indicate the relative location and orientation of the 270 12x24 inch pieces cut from block II of the Royal marble, Shelburne Marble Formation, Danby Quarry, Vermont. The top of the block is up; the north, east, south, and west sides (N, E, S, W) are as shown. The individual slabs from which the pieces were cut are shown by letter designation A through O (left of Fig.). Slabs A through N are 2 inches thick; the O slab is 4 inches thick. Within each slab the pieces are designated by letter relating to the slab and by two numbers. Thus, piece O3-6 is from slab O, NE corner of the block. The upper surface of each piece (designated by an arrow) is polished to an 80 grit finish.

Figure 6. Drawing of the briquettes sawn from the 2-inch thick slabs.

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UNITED STATES
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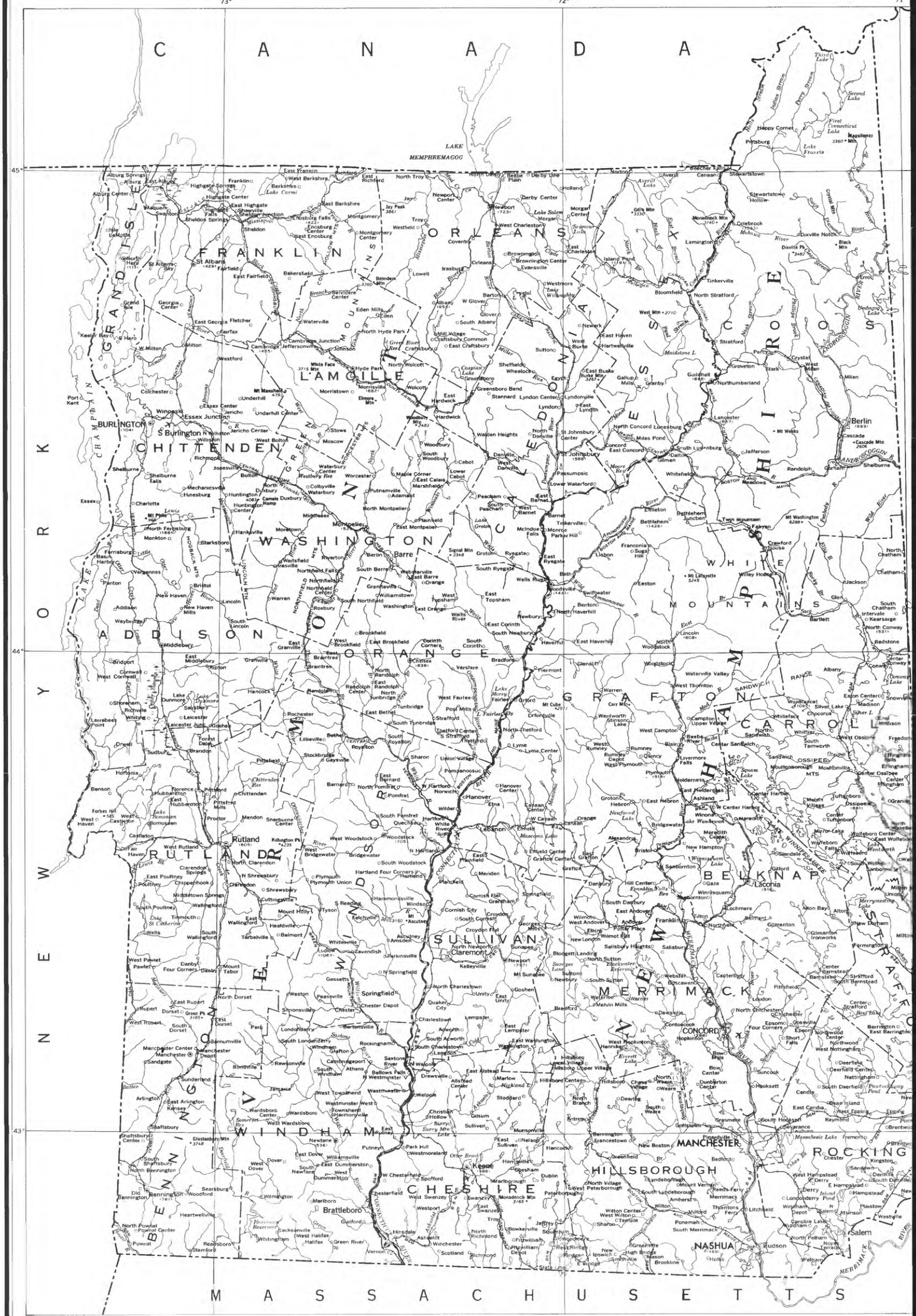
GEOLOGICAL SURVEY

STATES OF NEW HAMPSHIRE AND VERMONT



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Scale 1:1,000,000
1 inch equals Approximately 16 miles

10 0 10 20 30 40 Miles
10 0 10 20 30 40 50 Kilometers

Figure 1

DANBY QUARRY

SECTION SHOWING LAYERS AND VARIETIES

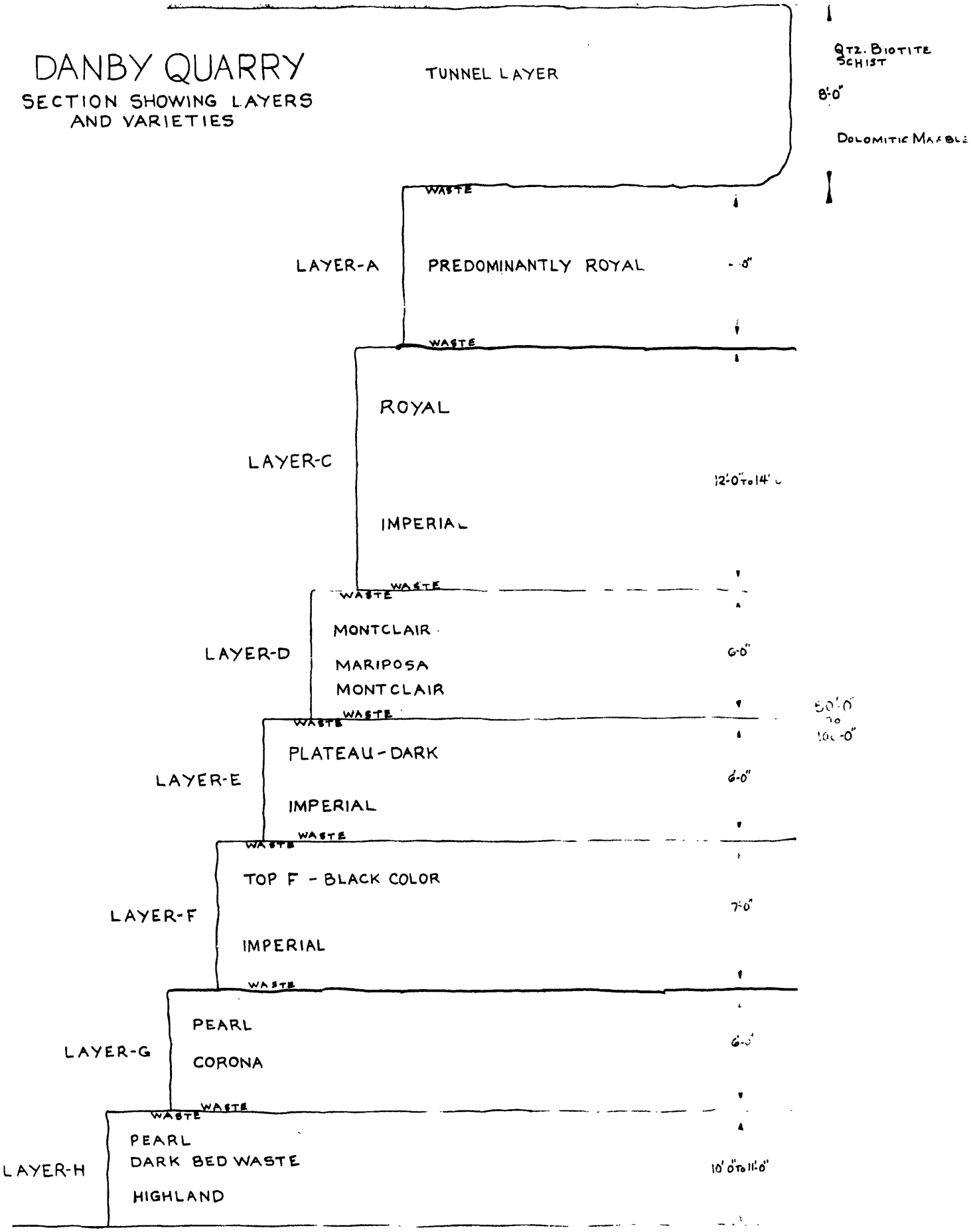


Figure 2

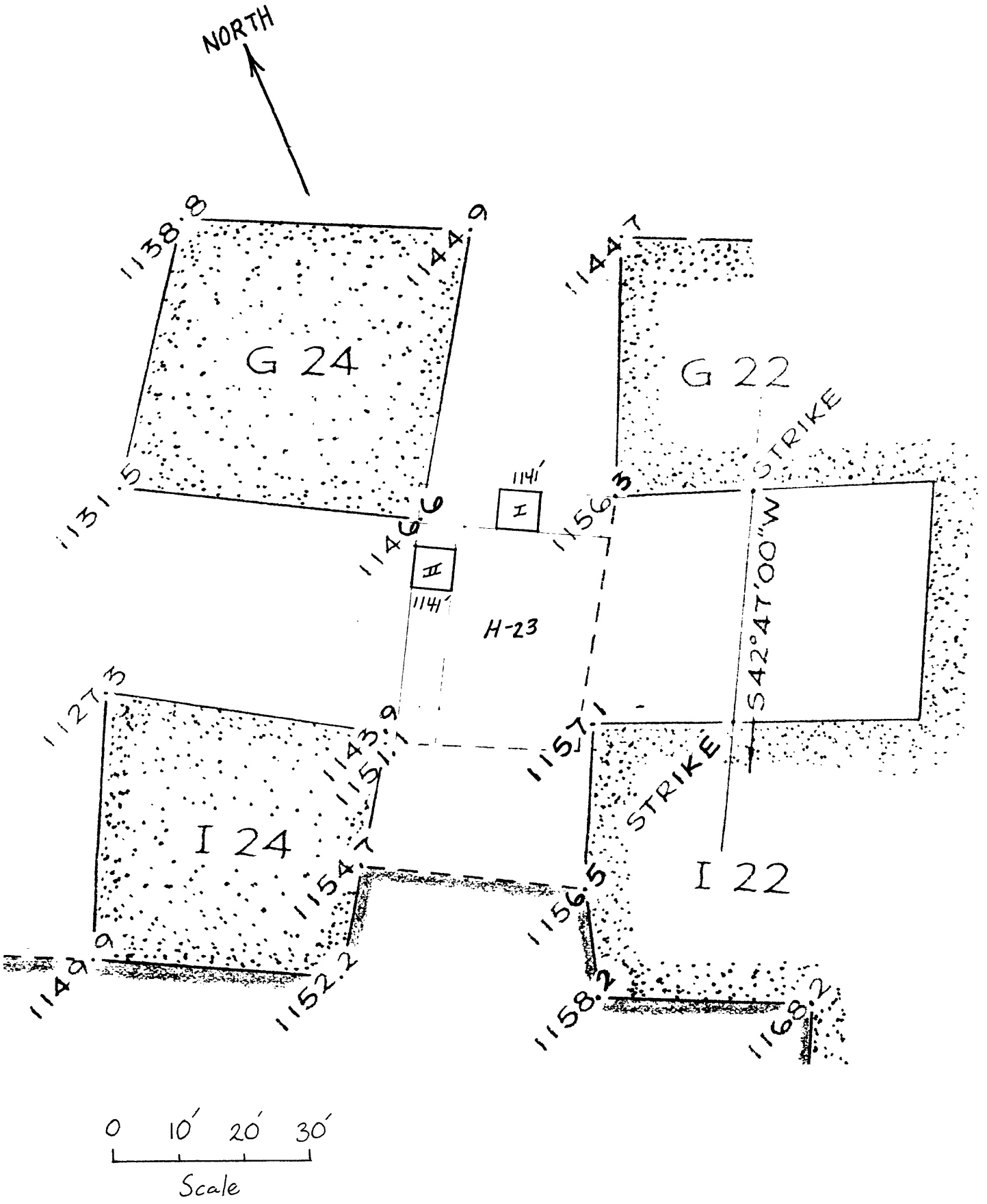
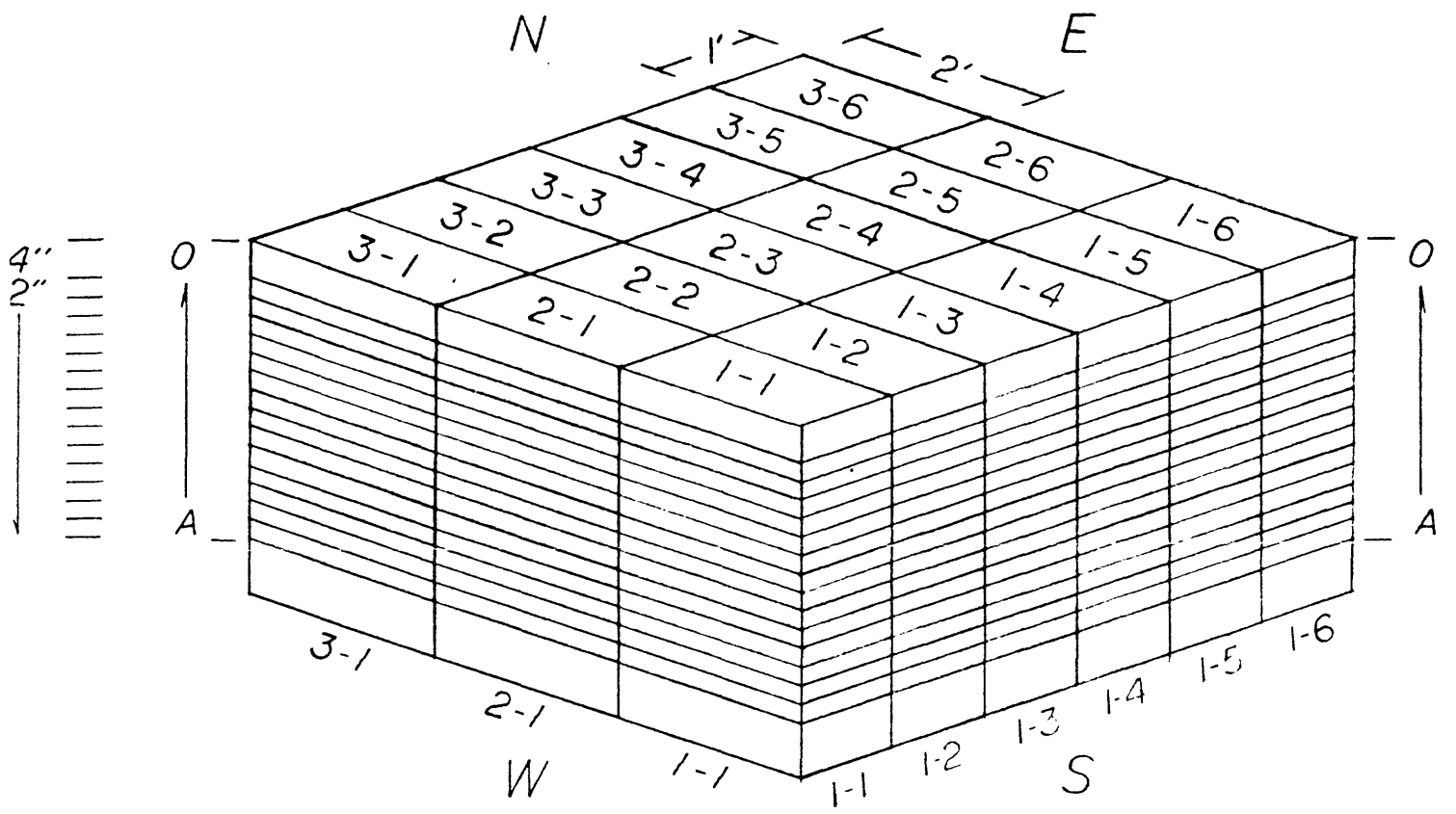
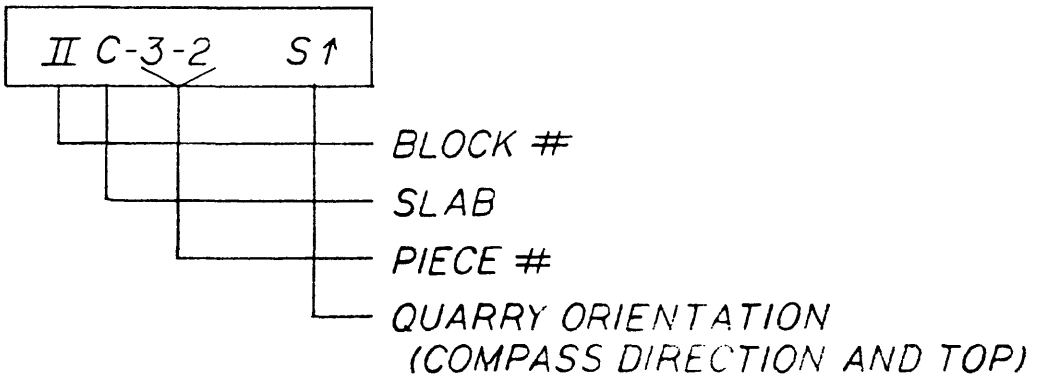

NORTH
1138.8
1144.9
G 24
1131.5
1146.6
1144.7
G 22
STRIKE
1141'
I
II
1141'
H-23
1156.3
S42°47'00"W
1127.3
1143.9
1151.1
1157.1
STRIKE
I 24
I 22
1154.1
1156.5
1149.9
1152.2
1158.2
1168.2
0 10' 20' 30'
Scale

Figure 3

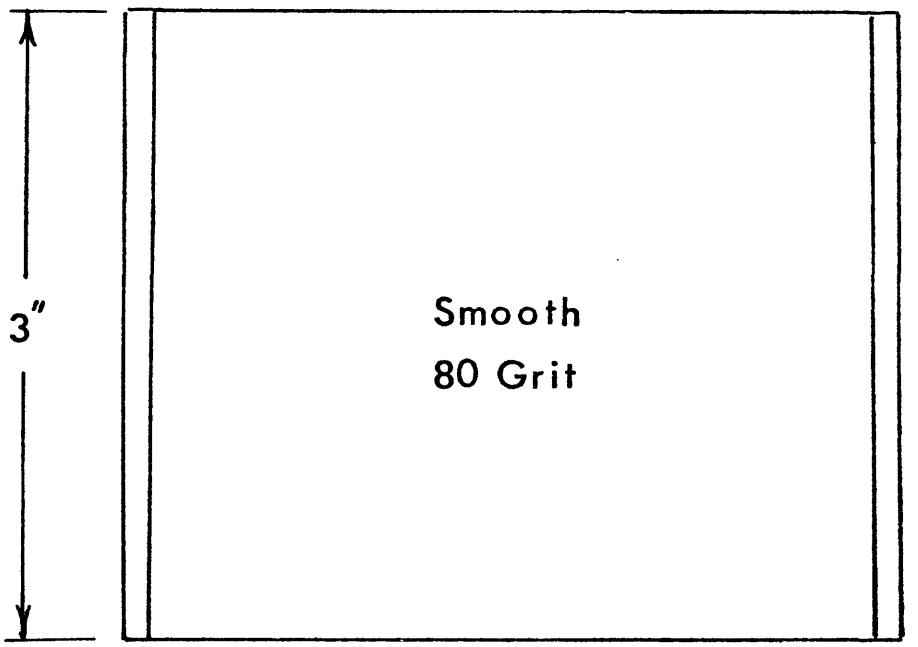
Figure 4





BLOCK II NUMBERING SYSTEM

Figure 5



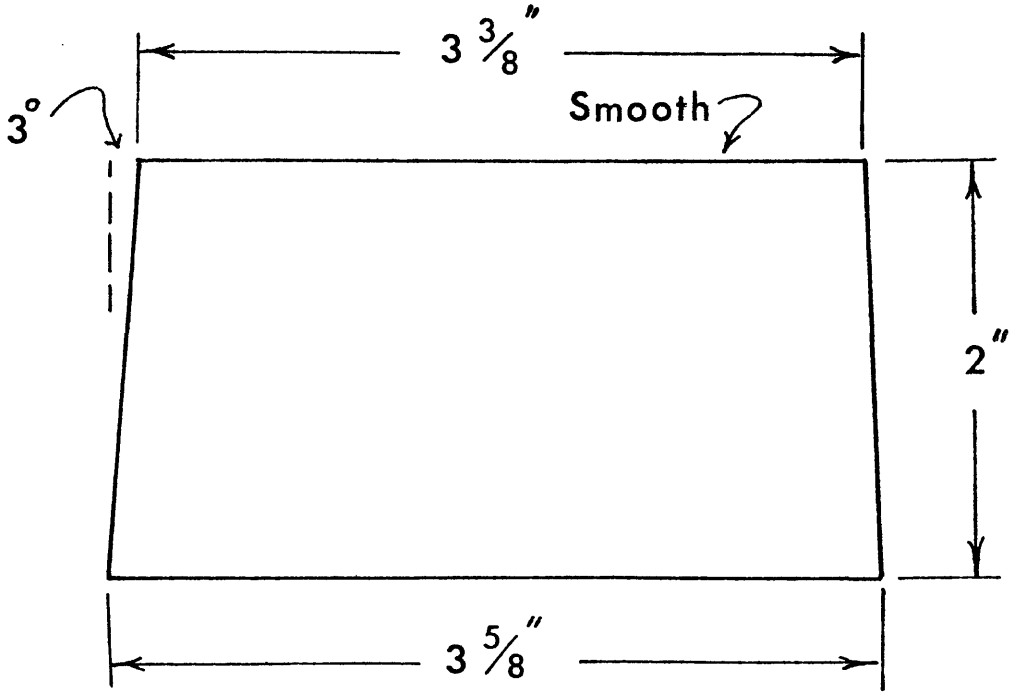


Figure 6