GEOLOGY FOR ENVIRONMENTAL PLANNING IN THE BURLINGTON-MIDDLEBURY REGION, VERMONT

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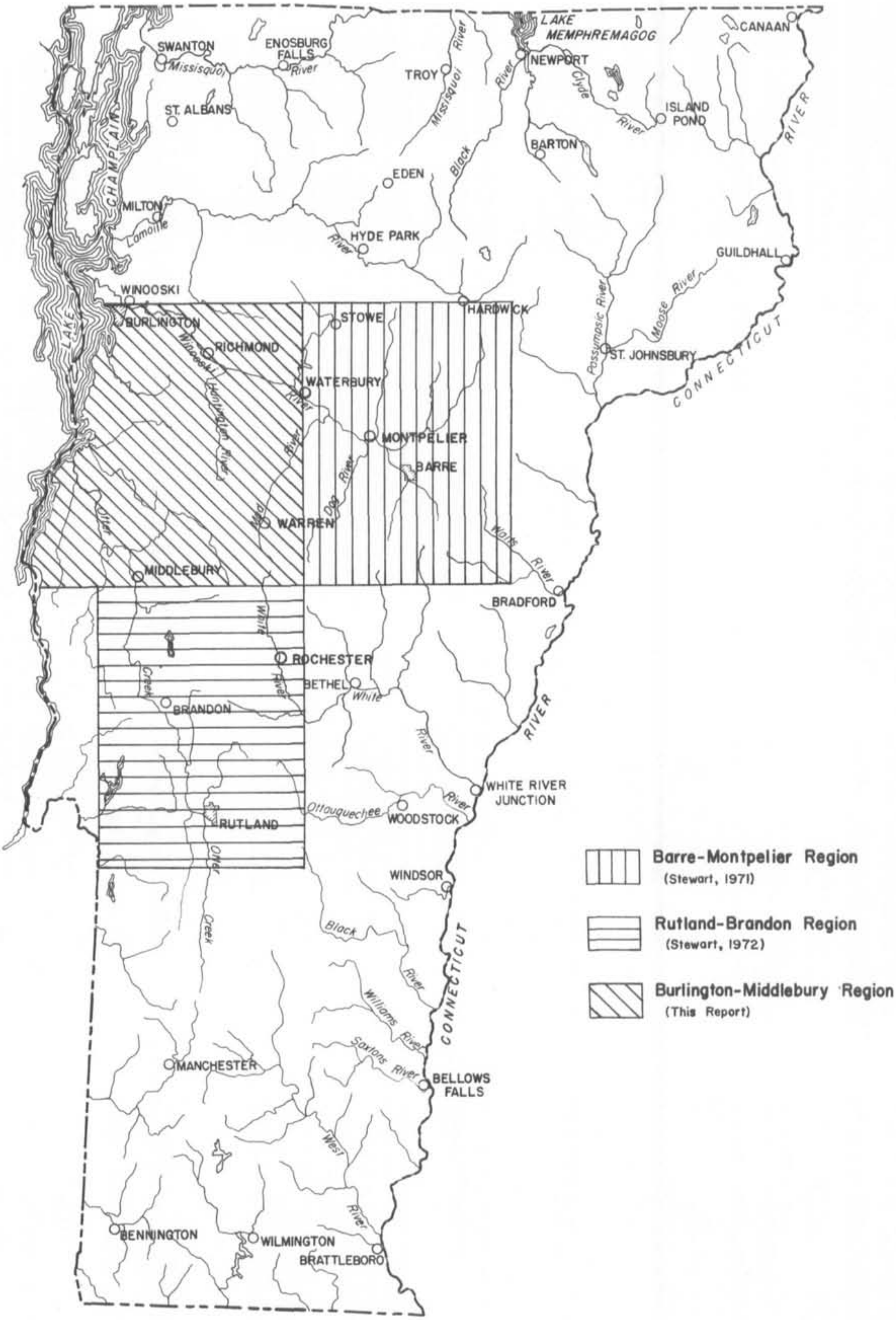

Figure 1. Index map showing regions where environmental studies have been completed.

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INTRODUCTION

This is the third report concerning a series of environmental studies sponsored by the Vermont Geological Survey. The first study was completed in the Barre-Montpelier region and a report was published in 1971. The second survey was in the Rutland-Brandon region and a report on this work was published in 1972. The present report, for publication in 1973, is concerned with the geology of the Burlington-Middlebury region (Figure 1). The purpose of these reports is to describe the geology of the region concerned and to outline the geologic conditions on a series of large-scale maps in such a way as to make the material available for use by planners. Inasmuch as planning agencies do not usually have geologists on their staffs, these reports attempt to supply the geologic background, in condensed and simplified form, necessary for adequate planning.

Geology is essential to certain aspects of environmental planning inasmuch as it is three dimensional and therefore includes the description of subsurface bedrock as well as the unconsolidated surficial material above it. The properties of the surficial materials and bedrock that relate to their water holding capacities and the movement of water through them is probably the most important single geological aspect of environmental planning. The availability of water, the contamination of water supplies, pollution from sewage systems and solid waste disposal operations are all related to the movement of water. The stability and strength of the surface materials are most important in the evaluation of foundation sites for heavy construction. In addition, the economically important geologic resources should receive major consideration in the planning for future use.

The regions that have been studied thus far were chosen because of the growth potential of those sections. It is unquestionably true that the Burlington-Middlebury region will be one of the areas of very rapid growth in the next decade or two. The fact is, expansion has already begun. Included in the region is the lake border of the Port Henry, Burlington and Middlebury quadrangles, and the mountainous terrain of the Camels Hump and Lincoln Mountain quadrangles.

The greatest concentration of population of the Burlington-Middlebury region is in the area that includes the cities of Burlington, South Burlington, Winooski, and Essex Junction. Already these four centers have been growing towards one another and, except for the Winooski River, their boundaries are becoming more and more obscure. Expansion of the population has already begun beyond the limits of these centers mostly on the lowland to the south. The village of Middlebury is the most southern point of high population density in the region. The village is growing and expansion beyond its limits has been about equal in all directions. Vergennes has also experienced growth adjacent to the city. But whereas the population spread in the vicinities of Burlington, South Burlington, Winooski, and Essex Junction has been generally southward into unpopulated rural areas, extending as much as 10 to 12 miles beyond city limits, the growth around Middlebury and Vergennes has been chiefly suburban in the immediate environs of these centers. Shelburne, south of Burlington, Ferrisburg and North Ferrisburg, north

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of Vergennes, are small centers of population but growth in these areas is also apparent, especially around Shelburne. It seems logical to assume that growth in the next decade or so will see much development on the entire Champlain Lowland between Vergennes and Middlebury. It is probable that the areas west of Otter Creek, south of Vergennes, except along State Route 22A and the lake shore, and west of Mt. Philo and Pease Mountain will remain agricultural, as indeed they should. Charlotte, Addison and Panton are small population centers in this section (Figure 2).

In the eastern part of the Champlain Lowland, Hinesburg and Bristol are small population centers that have experienced what seems to be the beginning of some growth. These centers, however, do not have enough industry to attract a large number of people and it is doubtful that growth will be large in the next decade. Starksboro, New Haven, and Monkton are rural communities in this section and they may remain so (Figure 2).

East of the Champlain Lowland, in the Green Mountains, concentrations of population are small and scattered except in Richmond, Waterbury, the Mad River valley south of Moretown, and to some extent the Huntington River valley. Growth in the Mad River valley, in recent years, has been second only to the Burlington-South Burlington-Winooski-Essex Junction area. The increased population in the valley, however, has been, and will continue to be, the result of winter sports activities. There are three large ski developments on the east slope of the middle ridge of the Green Mountains in this section. These are the Glen Ellen, Mad River Glen, and Sugar Bush operations that have constructed ski trails over most of the distance between Appalachian and Lincoln gaps making it one of the largest and most popular ski regions of the eastern United States. Contemporaneous with the development of ski areas has been the growth of housing projects both in the valley and on the mountain sides. In spite of the growth, the whole section is still considered rural since there is no regional water or sewage system. Population centers in the valley that antedate the ski development are Moretown, Waitsfield, Irasville, and Warren.

Richmond, in the Winooski Valley, is developing as a residential community because of its nearness to Burlington and Essex Junction. Waterbury has also grown slowly because of a slight increase in the industrial facilities in the area. Rural villages in the mountains include Jericho Center, north of the Winooski River, Huntington and Huntington Center in the Huntington River valley, and Lincoln, South Lincoln, and Jerusalem on the west slope of the mountains east of Bristol.

The fieldwork for this report was completed by the writer, assisted by Terry M. Kramer and Alan P. Egler during the summer of 1972. The work was under the direct supervision of Dr. Charles G. Doll, the State Geologist.

SOURCE OF MATERIAL

The data used in the preparation of this report and the accompanying planning maps were collected and assimilated from many different sources. As a general rule, there is much material already available from various federal, state, and local agencies related to environmental problems. Much of this material is too technical to be used by planners or it is not known to exist. In Vermont, much useful material is available from the Vermont Geological Survey, the Vermont Water Resources Department, and regional offices of the United States Conservation Service.

Bedrock data were obtained mostly from the *Centennial Geologic Map of Vermont* (Doll, Cady, Thompson and Billings, 1961). The Centennial Geologic Map gives formation names, stratigraphic and age relationships, and the description of each unit. Much of this material is technical and might be somewhat confusing to planners without geology backgrounds. The bedrock map was therefore considerably modified to make it more adaptable for planning use (Plate II).

The surficial geology of the Burlington-Middlebury region was mapped during the program that produced the *Surficial Geologic Map of Vermont* (Stewart and MacClintock, 1970). The writer mapped the Camels Hump, Burlington and Willsboro quadrangles, MacClintock mapped the Port Henry and the southern one-third of the Lincoln Mountain, and Calkin mapped the Middlebury and the northern two-thirds of the Lincoln Mountain quadrangles. (Stewart and MacClintock, 1969, p. 14.) The surficial maps were checked in the field and adapted for environmental use. The explanations of these maps were simplified to some extent and the descriptions of the materials were modified to include properties that are directly applicable to the environment (Plate I).

It was planned that percolation tests would be made at irregular intervals over the whole region to determine the texture, permeability, and other water related properties of the top three feet of the surface material. A four-inch auger mounted on the back of a Jeep was available for this use. During the spring and summer of 1972, however, rainfall in the region was much above normal. As a result, the top three feet of the surface material remained saturated during the entire field season. Lake Champlain maintained a level three to five feet above normal, and, in the sections with clay surface material, water covered the surface depressions most of the summer (Figure 3). Percolation tests were therefore impossible.

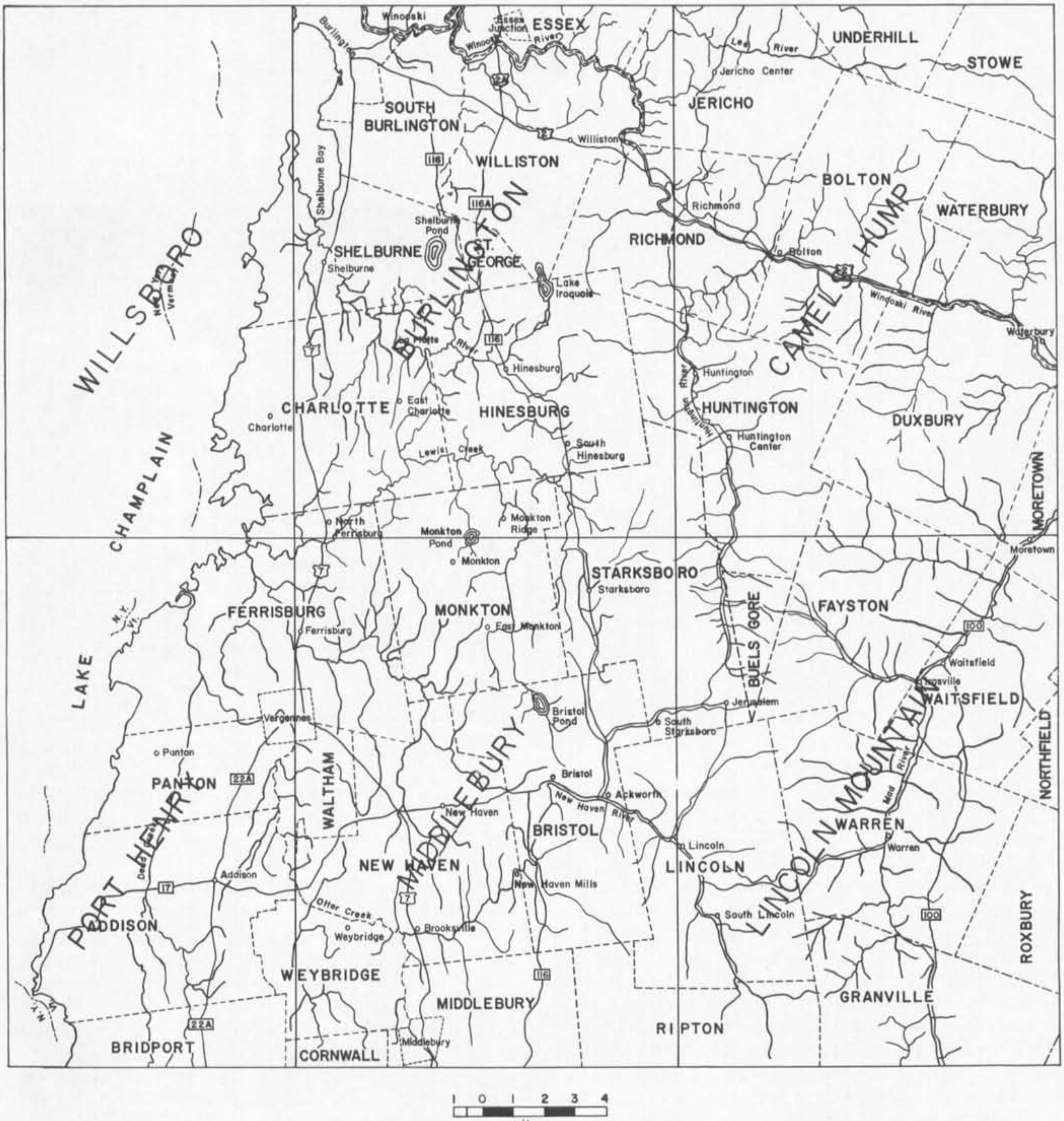

Figure 2. Index map showing the location of quadrangles, townships, cities and villages in the Burlington-Middlebury region.

Water-well records, on file at the Water Resources Department, were studied to ascertain water potentials. The information was used for comparison with and the modification of existing ground water favorability maps (Hodges, 1967; Hodges and Butterfield, 1967, and 1968). The logs were also used to determine, where possible, the depth of the water table, the thickness of the surficial material above bedrock, and to assist in locating desirable localities for seismic study. This information was necessary to construct a ground water potential map (Plate III).

Sand and gravel deposits were studied to determine the quality of the material as well as the reserve available. Localities of possible economically important mineral and rock deposits were mapped (Plate VII).

Existing solid waste disposal sites were evaluated

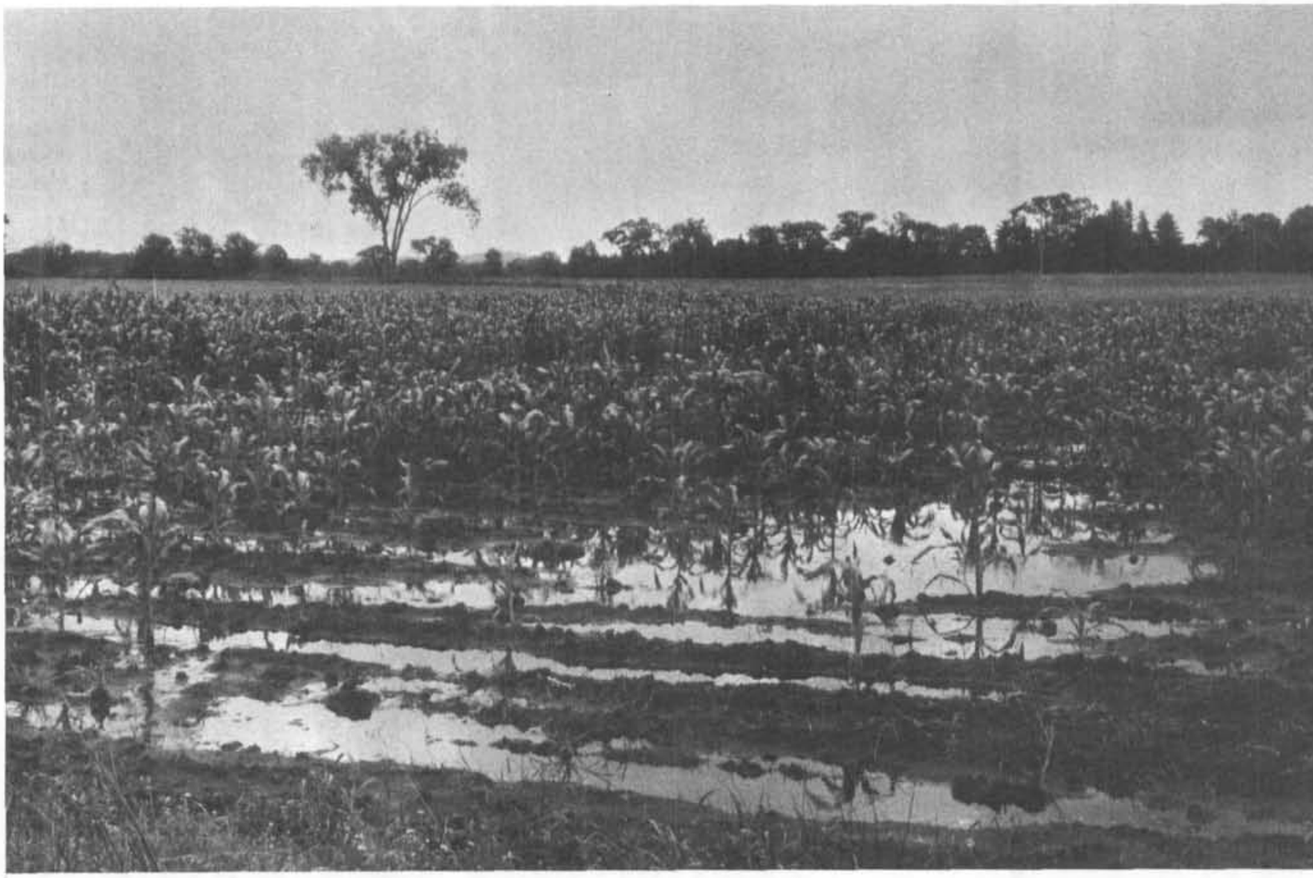

Figure 3. Cornfield inundated by water, July, 1972. Clay soil could not absorb water rapidly enough during the wet summer season. Four miles west-southwest of Addison.

in reference to the geology in the section in which they were located. Sewage disposal practices for domestic installations (septic tanks, dry well, etc.) were studied (Plates IV and V).

Thirteen localities were selected for seismic study to ascertain ground water characteristics and thickness of overburden. The seismic work was done by the Weston Geophysical Engineers, Inc. of Weston, Massachusetts. The twelve point seismic refraction method was employed using a portable twelve-channel seismograph. The refraction method is an indirect means of determining the depth to bedrock and the depth to seismic discontinuities (contacts between layers of different properties caused by water saturation and textural changes in the unconsolidated sediment above bedrock). The profiles reproduced in this report are those made by the Weston Geophysical Engineers during the seismic work (Weston Geophysical Engineers, 1972).

EXPLANATION OF THE PLANNING MAPS

A series of maps has been prepared to illustrate the geology and the environmental conditions in the Burlington-Middlebury region. Plates 1 through VII in the pocket at the end of this report are planning maps showing the surficial material, the kind of bedrock, the ground water potential, the suitability of the different sections of the region for various uses, and the distribution of sand and gravel deposits. The color schemes on the maps (Plates III, IV, V, and VI), green for go, yellow for caution, and red for stop, were copied, in modified form, from the Illinois Geological Survey reports (Hackett and McComas, 1963; Jacobs, 1971). Areas shown in green are interpreted as offering minor problems and minimum limitations. Sections shown in yellow have moderate to fairly severe limitations, but the problems are, as a general rule, controllable. These areas require detailed study to ascertain the limitations and to determine the necessary controls. Areas mapped in red have severe limitations and many problems that are impractical to overcome. These areas should be avoided in most cases. Where two or more different symbols are used for the same color, for example g-1 and g-2, it is to show different conditions with different problems, but not necessarily more (or less) limitations. These maps, of necessity, are quite generalized and do not eliminate the need for detailed study of each locality as development is planned.

The maps of the surficial material (Plate I) and

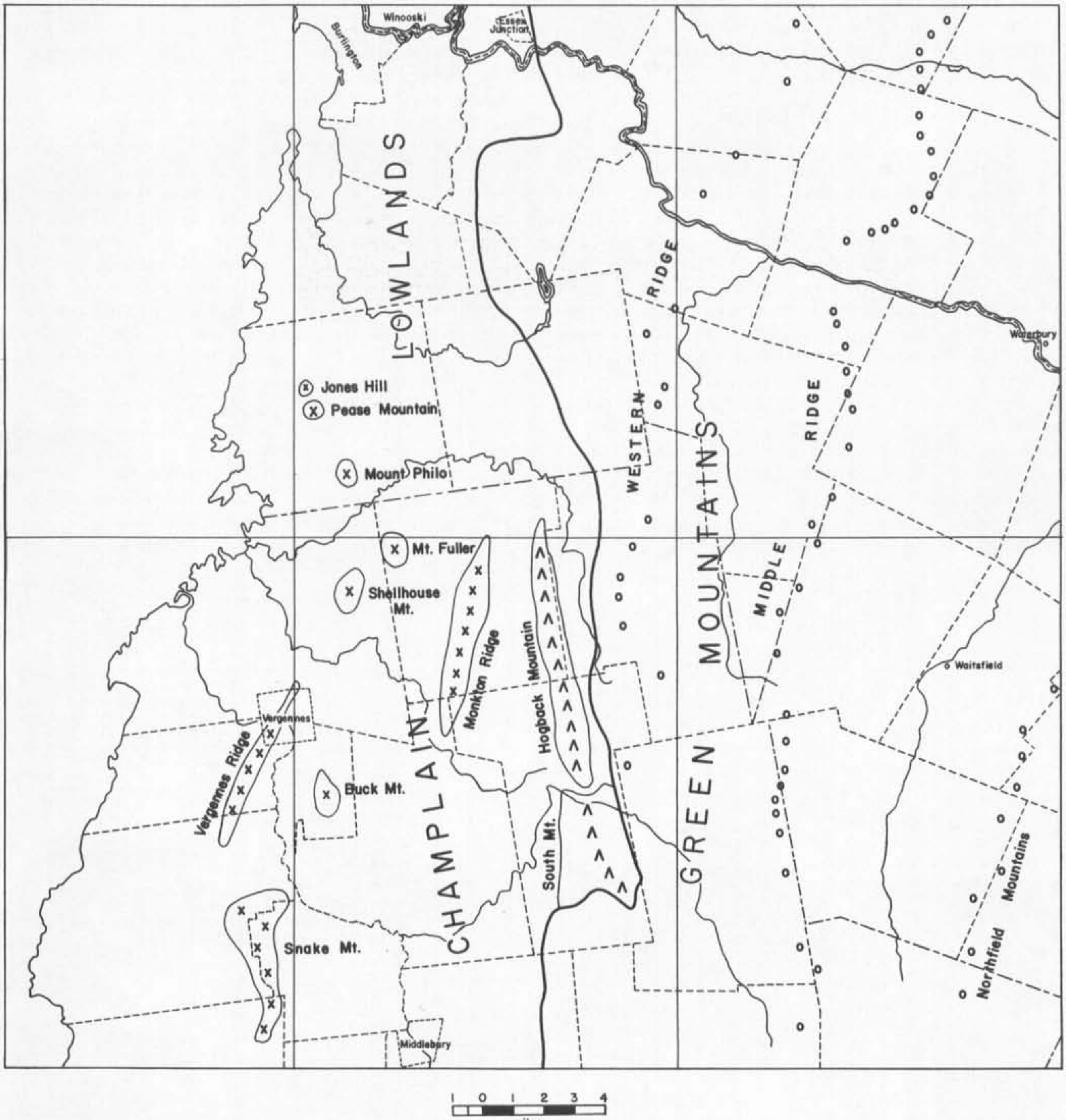

Figure 4. Geomorphic subdivisions and major topographic features of the Burlington-Middlebury region.

bedrock map (Plate II) show the distribution of the various types, since each kind of bedrock and surface material has different characteristics insofar as the environment is concerned.

GEOLOGIC SETTING

There are two distinctively different geomorphic subdivisions in the Burlington-Middlebury region. These are the Champlain Lowland on the west and the Green Mountains on the east (Figure 4). The two subdivisions have quite different topography, bedrock and structure, and any one of these factors could be used as a criterion for separating the two sections. The Green Mountain province is by far the more complicated due to the fact that the sediments composing it were deposited in a more tectonically active environment and the mountains have undergone a more intense geologic history. Several episodes of mountain building have been recorded, accounting for the highly altered rock and complex structures. In contrast, the rocks of the Champlain Lowland have had much less metamorphism and the structure of the rock layers varies between horizontal and gently tilted.

Champlain Lowland

The Champlain Lowland is not a lake plain in the ordinary sense of the word because the surface is not level. Irregular topography that includes hills and low mountains with conspicuous relief and sharp, bold slopes are common. Many of the hills and low mountains of the lowlands are erosional remnants of former ridges caused mostly by faulting, displacement along fractures in the rock. The rocks forming the former ridges were dislocated by compressive stresses and pushed westward along low-angle fracture zones. As a result, the dip (inclination) of the rock in the faulted block is usually eastward (Figure 5) and the hills thus formed have a steeper slope on the west side than on the east.

On the lowland adjacent to the hills, the topography varies between level and rather rugged depending on the type of bedrock, the kind and thickness of the sediment covering bedrock, and the amount of erosion. Much of the sediment above bedrock is lake or marine detritus with an original level surface. In some places, the erosional topography is carved into bedrock whereas in other localities erosion is limited to the surficial material covering it.

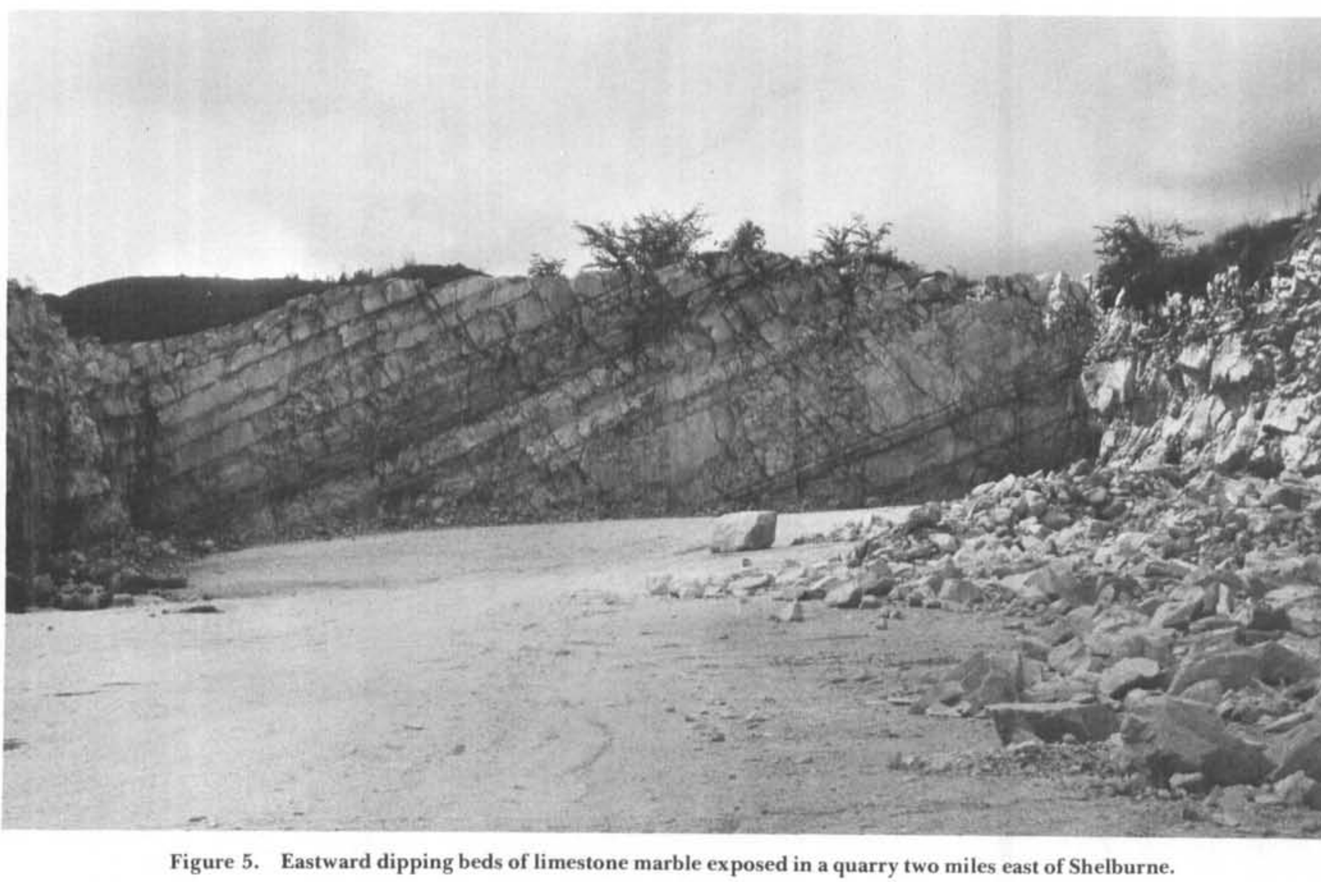

Figure 5. Eastward dipping beds of limestone marble exposed in a quarry two miles east of Shelburne.

Figure 6. Snake Mountain rising conspicuously from the Champlain Lowland. Quartzite and dolomite rock are exposed along the crest. Picture taken looking east from Dead Creek, two and one-half miles southwest of Addison.

Figure 7. Small solution cavern at the contact of the Hinesburg thrust at Mechanicsville. Complex rocks of the Green Mountains (above) thrust over dolomite of the Champlain Lowlands.

The structural relationships of the rocks of the Champlain Lowland are by no means simple. In general, gross features of the structure, formed before the faulting, include two large structural basins (synclinoria) separated by a bedrock arch (anticline). The southernmost of the bedrock basins is called the Middlebury synclinorium and this structure accounts for the elliptical pattern of the bedrock in the western half of the Middlebury Quadrangle (Plate II). According to Cady (1945, p. 562), the basin covers the area south of the latitude of Hinesburg between the Green Mountains on the east and Snake Mountain on the west. The structure is designated a synclinorium because there are folds superimposed on both sides of the basin. The second bedrock basin is the Hinesburg synclinorium that trends northward from the latitude of Monkton and extends across the lowland between Lake Champlain and the Green Mountains (Cady, 1945, p. 562). The two basins are separated by a bedrock arch called the Monkton cross-anticline.

After the initial deformation that formed the synclinoria and the anticline, the area was subjected to compressional stresses that formed low angle thrust faults. The stresses must have come from the east inasmuch as the rock slice above the fault surface was thrust westward over the bedrock below. One of these faults, the Champlain thrust, extends from a short distance south of Snake Mountain to the Canadian border with a trend that roughly parallels Lake Champlain (Welby, 1961, p. 193). The western edge of this body of rock thrust westward by the faulting (overthrust sheet) is marked by a chain of hills (or low mountains) that include, from south to north, Snake (Figure 6), Buck and Shellhouse mountains, Mt. Fuller and Mt. Philo, Pease Mountain and Jones Hill (Figure 4). This fault, known internationally, is best displayed in Burlington at Lone Rock Point.

To the east, the Hinesburg-Oak Hill thrust marks the boundary between the lowland and the Green Mountains north of Hinesburg. The south end of this fault lies three or four miles south of Hinesburg (Cady, 1945, p. 566), and the Green Mountain front in this section is actually material that was thrust over the rocks of the lowland. Cady (1945, p. 566), suggested that the name Hinesburg should be used to designate the fault south of the Winooski River and Oak Hill for that part north of the river. In common usage, however, the two terms have been used interchangeably. In the vicinity of Hinesburg, the complex rock of the overthrust sheet can be seen resting on the dolomite rock of the lowland and the contact is marked by small solution caverns in the dolomite (Figure 7).

Three smaller structures that are important in explaining the topography of the Champlain Lowland are the Hogback anticline, the Monkton thrust, and the Vergennes thrust. The Hogback anticline is the structure that brings quartzite to the surface in Hogback and South mountains on the western side of the lowland north and south of Bristol (Figure 8). The mountains formed by this structure, particularly South Mountain, because of their bold relief appear to be part of the Green Mountains, but the bedrock is definitely that of the lowlands. The Monkton thrust extends from a point one mile northeast of New Haven to the village of Monkton. The overthrusting in this short section has exposed resistant quartzite that forms the hills south of Monkton Pond, called Monkton Ridge in this report (Figure 4). The Vergennes thrust trends north-northeast from near Addison village through the city of Vergennes to the village of Ferrisburg (Cady, 1945, p. 514). This feature forms the ridge trending south-southwest from Vergennes to Addison and is designated the Vergennes Ridge on the geomorphic map (Figure 4).

In addition to the thrust faults, the region has been cut into a series of blocks by high angle faults that trend north-northeast (Welby, 1961, p. 199). These are parallel (longitudinal) to the major structures of the region and cut through the overthrust sheets. There is also a series of high angle faults trending east-west that intersect the thrust slices, folded strata and longitudinal faults at about right angles. Jointing, fractures without displacement, is also common to the rocks of the lowland. Joints trending east-west are abundant throughout the region and in the western part of the lowland north-south joints are equally prevalent.

Green Mountains

The major structure of the Green Mountains is described as an anticlinorium: a very large bedrock arch, or upfold, with superimposed folds across its entire width. The axis of the anticlinorium trends generally north-south and roughly parallels the middle ridge. According to Christman (1961, p. 47), the folding does not have a single axis, but it consists of a series of axes that are offset from one another. Inasmuch as the structure is an anticlinorium, it is not a single fold but instead a series of smaller folds on the great arch. Christman (1961, p. 48), for example, mapped two synclines and an anticline on the west side of the anticlinorium in the northwestern part of the Camels Hump Quadrangle but only a syncline in the southwestern part of the map.

The rocks and their structures are so complex as a result of severe deformation that the structures described above are not apparent in most localities except to a trained geologist. The complexities of the mountain region can probably best be understood by noting that studies made by Christman (1960) and Osberg (1952), for example, record secondary structures such as schistosity, drag folds, fracture cleavage, and jointing as being common to all areas of the mountains.

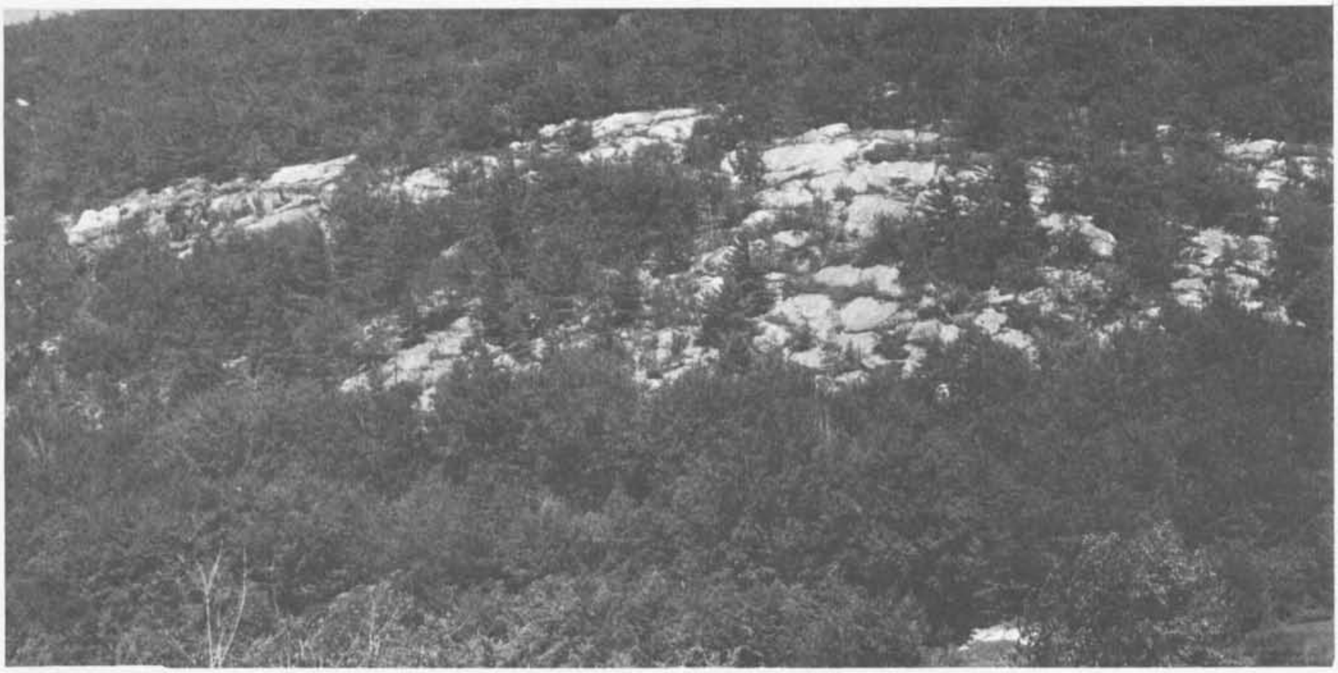

Figure 8. White quartzite bedrock on the west slope of Hogback Mountain four miles north of Bristol.

Figure 9. Fractured limestone marble exposed in a quarry two miles north of Brooksville.

Figure 10. Camels Hump from Interstate Highway (I-89). Picture taken looking southwest three miles east of Bolton.

The bold western front of the western, or first, range of the Green Mountains is not as apparent in the Burlington-Middlebury region as it is in the region immediately to the south (Stewart, 1972, p. 10). The bold front continues into the Middlebury Quadrangle for about five and one-half miles where it is cut off abruptly by South Mountain. The Little Notch Road, four miles south of Bristol, skirts the south end of South Mountain. As already noted, this mountain is a folded structure exposing Champlain Lowland rock and is therefore not a part of the Green Mountains. At Bristol, the western ridge offsets to the east and is more or less continuous in a series of high knobs west of the Huntington River valley to Richmond. A series of hills with crest elevations 1500 to 2000 feet, much lower than the middle and eastern ranges, may be traced from south to north from Bald Hill, east of Bristol, through Norton Hill, East Mountain, High Knob, and Shaker Mountain. North of Richmond the ridge is less conspicuous except at Huckleberry Hill and Bald Hill east of Jericho.

The middle range forms the high crests of the Green Mountains trending north-south across the central portion of the Camels Hump Quadrangle and a short distance west of center in the Lincoln Mountain Quadrangle. It is the highest and most conspicuous ridge of the Green Mountains and has been called the backbone of the topography of Vermont. Except for Mt. Mansfield, a few miles to the north and Killington Peak to the south, the highest and most rugged part of the middle ridge lies in this section. That part of the range known as Lincoln Mountain, between Lincoln Gap and Appalachian Gap, is probably the most rugged part of its entire length in Vermont with the summits of Mt. Ellen, Cutts Peak, Mt. Abraham and Lincoln Peak all standing above 4000 feet. To the north, Camels Hump rises to an elevation of 4083 feet only three and one-half miles south of the Winooski River where the elevation is a mere 340 feet (Figure 10). Other heights on the middle ridge include (north to south) Bolton Mountain (3725), Mt. Ethan Allen (3688), Stark Mountain (3585), Nancy Hanks Peak (3860), Mt. Grant (3660) and Mt. Roosevelt (3580).

The eastern, or third, range of the Green Mountains is manifested in the Northfield Mountains that lie along the eastern border of the Lincoln Mountain Quadrangle. Inclusion of this range in the Green Mountain province is in accordance with Jacobs (1950, p. 74), a classification about which there is disagreement. The Northfield Mountains are considered a part of the Green Mountains in this report because of the similarity of the structure and bedrock. The highest crests of the third range are generally at elevations between 3000 and 3700 feet in the southeastern corner of the Lincoln Mountain Quadrangle. Rice and Adams mountains rise to 3060 and 3236 respectively in that area. North of Rice Mountain the crests are between 2600 and 2900 feet to Scragg Mountain (2920), and farther north the elevations are below 2500 feet. The only road across the range in this area is through Roxbury Gap at 2416 feet.

Environmental Significance of Structures

The above brief discussion concerning the structures of the rocks in the Champlain Lowlands and the Green Mountains emphasizes the fact that the whole region has been subjected to great stresses and that the rocks have been folded, faulted, jointed, crushed, and broken (Figure 9). Since the rocks are metamorphosed, they do not contain pore space between the grains in which water can be held or through which water can move. Instead, the water in the rock can only be held and move through the various types of fractures. This is of great importance as it relates to the ground water supply and its pollution from solid waste disposal installations and sewage systems. These aspects of the rock properties and their relation to environmental planning will be treated at length in the chapters that follow.

DRAINAGE

The drainage pattern in the Burlington-Middlebury region is complicated by the rugged topography of the Green Mountains, the thrust faulting of the Champlain Lowland, and the drainage changes caused by multiple glaciation. Inasmuch as drainage is a factor that must be considered when planning, the drainage basins and the important tributary basins (composing them) are delineated on the drainage map (Figure 11).

The Winooski River and its tributary streams drain approximately one-half of the area covered by the present study. The river enters the region at Waterbury and flows generally west-northwest through the Green Mountains in a deep, steep-walled water gap to Richmond. It is interesting to note that the highest segments of the entire mountain chain lie immediately to the north and south of the river. The steep valley walls of this reach of the river and the adjacent tributaries have increased the ruggedness of the topography, cut the mountain into distinct sections and increased runoff and erosion from precipitation.

Two major tributaries, the Mad and Huntington rivers, drain the mountainous terrain south of the Winooski Valley. The most easterly of these, Mad River, heads at the north end of Granville Gulf near the southeast corner of the Lincoln Mountain Quadrangle. The river drains the basin between the middle range on the west and Northfield Mountain on the east and tributary streams extend almost to the crests of the mountains on both sides. From its head, the river flows northward to Warren and then north-northeast through Irasville, Waitsfield, and Moretown and leaves the region about one mile northeast of Moretown. The Huntington River, the second major tributary to the south, drains the western side of the middle range and the eastern side of the western range, and the low foothills to the west. The river originates in Buels Gorge on the west slope of Stark Mountain and flows northward past Huntington Center and Huntington. Three miles north of Huntington the river turns and flows northeast to the Winooski River at Jonesville.

The northeast corner of the Camels Hump Quadrangle is drained by tributary streams of the Waterbury River, a tributary of the Winooski. Other short streams flow from the north and south into the Winooski River to drain the sections adjacent to the valley. One exception is Mill Brook that heads on the west slope of Bolton Mountain and flows westward, south of the Lee River Basin, to enter the Winooski one and one-half miles northwest of Richmond.

Only a small area along the northern border of the Camels Hump Quadrangle and the southeast corner of the Lincoln Mountain Quadrangle drain away from the Winooski Basin. The Lee River heads in the town of Underhill, on the west slope of the middle range, and flows westward to Browns River near the village of Jericho. This drainage flows north to the Lamoille River. Most of the drainage in the southeast corner of the region flows southward and eventually into the Connecticut River. Tributaries of the Third Branch of the White River begin on the eastern slopes of Northfield Mountain, but the main stream flows for only three miles through the area mapped. The Dog River, a tributary of the Winooski, also originates on the east slope of Northfield Mountain. Streams flowing south and southwest from Granville Gulf flow a short distance into the White River.

West of Richmond, the Winooski River flows north through the foothills of the Green Mountains to North Williston and then west-northwest to Essex Junction. One mile east of Essex Junction the river flows onto the Champlain Lowland, crosses a bedrock falls just south of Essex Junction, and then meanders across a fairly wide valley. At Winooski, however, the valley narrows and the river flows through a winding gorge about one mile long. West of the gorge the valley again widens and the river flows west for approximately one mile where it turns north and leaves the region west of Winooski. The origin of the gorge at Winooski is, as yet, not understood, but it seems probable that this is a rather recent channel and that

Figure 11. Drainage basins of the Burlington-Middlebury region.

an older, buried valley may exist north or south of the gorge.

Three important tributaries of the Winooski River drain portions of the Green Mountain foothills and the Champlain Lowland south and west of Richmond. Johnnie Brook drains the foothills immediately to the south of Richmond. Allan Brook heads in the foothills two miles north of Lake Iroquois and flows north-northeast to Williston and then west and northwest to the Winooski River two miles southwest of Essex Junction. Muddy Brook starts in Shelburne Pond and flows almost due north to the river southwest of Essex Junction.

Otter Creek and its tributaries drain the southwestern part of the Burlington-Middlebury region (Figure 11). The stream enters the Middlebury Quadrangle south of Middlebury and flows north through Middlebury to Brooksville and then westward to the base of Snake Mountain, where it again flows north to Vergennes and then west for three miles before turning north to Lake Champlain. The New Haven River, a thirty mile-long tributary of Otter Creek, drains a large section east of Middlebury, New Haven, and Bristol. The river heads on the north slope of Bread Loaf Mountain, five miles south of South Lincoln, and flows north-northwest through South Lincoln, Lincoln, and West Lincoln, to Bristol. The stream turns south at Bristol and flows generally south and south-southwest through New Haven to enter Otter Creek about a mile west of Brooksville. Dead Creek, another tributary of Otter Creek, drains the lowland west of Snake Mountain and Addison Ridge.

The Champlain Lowland between Vergennes and Bristol is drained by Little Otter Creek. The stream originates immediately to the northwest of Bristol and flows in a generally northwest direction to Lake Champlain at Hawkins Bay. The basin drained by this stream is odd-shaped because of the fault-block topography of the lowland. It flows south of Mt. Fuller and Shellhouse Mountain, south and west of Monkton Ridge, and north of bedrock highs between Bristol and Weybridge.

Lewis Creek, which empties into Lake Champlain less than one-half mile north of the mouth of Little Otter Creek, drains a large area north of the Little Otter Creek Basin. The creek actually heads in the Green Mountain foothills east of State Route 116 between South Hinesburg and Starksboro, and headwater streams drain the valleys east and west of Hogback Mountain. The stream is 22 miles long and drops 1800 feet from head to mouth. The east-west valley now occupied by Hollow Brook, a tributary of Lewis Creek, is one of the most interesting geomorphic features of the region. The deep, steep-sided valley, directly east of South Hinesburg, must mark the position of a former drainage of considerable size, possibly the pre-glacial Huntington River.

The LaPlatte River follows the course of a deep, pre-glacial valley that is now filled with glacial, glaciofluvial and/or lacustrine sediments. In the Hinesburg and Shelburne sections of the valley the fill is gravel, probably outwash, but in between lake silts and clays fill the valley. The river heads north of South Hinesburg in the kame terrace of that area and flows northwestward to the south end of Shelburne Bay. A major headwater tributary, Patrick Brook, drains the Lake Iroquois-Lower Pond basin and enters the river just west of Hinesburg.

The Lake Champlain shore is drained by numerous small streams some of which are intermittent and most of them are too small to have names. One five mile-long section of the shore between Shelburne and Burlington, for example, is drained by no less than seven small streams and only two of them are named. Farther south, particularly in the Port Henry Quadrangle, the lake shore area is drained almost entirely by small intermittent streams and gullies.

BEDROCK

As already stated, there are two distinctly different rock sequences in the Champlain Lowland and the Green Mountains. The rocks of the lowland are only slightly metamorphosed and, except for some slate, they are nonfoliated. The rocks of the Green Mountains, in contrast, are complex crystalline, mostly foliated, and a large percentage of the minerals composing them were formed as a result of metamorphism. There are two chief reasons for the differences between the rocks of the two regions. In the first place, the rocks of the two provinces were deposited in different sedimentary environments; the Green Mountain sediments having been deposited in a more tectonically active basin. Secondly, the Green Mountain region has been subjected to much greater and more intense deformation than that of the lowland. As a result, the two provinces can be delineated solely on the basis of rock types as was done on the geomorphic map of this report (Figure 4).

The bedrock map prepared for this report (Plate II) is not a geologic map in the sense that it gives the names of the individual rock layers and shows their age relationships. Instead, the map purposely avoids such usage since formation names and geologic ages are of little value to planners. The lithologies of the various rocks and their physical description, with significant chemical properties, is all that the bedrock map is intended to show. It is believed that this map, modified from the Centenial Geologic Map of Vermont (Doll, Cady, Thompson and Billings, 1961) will prove to be much more practical for use by planners. If more detailed information is needed, it is available on the Centennial map.

Interestingly enough, there is evidence of igneous activity in the Champlain Lowland inasmuch as there are tabular shaped veins of igneous rock, called dikes, that cut across the rock layers (Figure 12). The dikes occur at irregular intervals and are more common in some localities than in others. The most common type dike is composed of material called Bostonite that has a reddish brown color and fine texture. Other dikes are composed of fine-grained, dark grey material called Camptonite.

Rocks of the Champlain Lowland

The rocks of the Champlain Lowland are characteristically a sequence of carbonate rock, composed of both limestone and dolomitic marbles, with an occasional quartzite or slate. The ages of the lowland

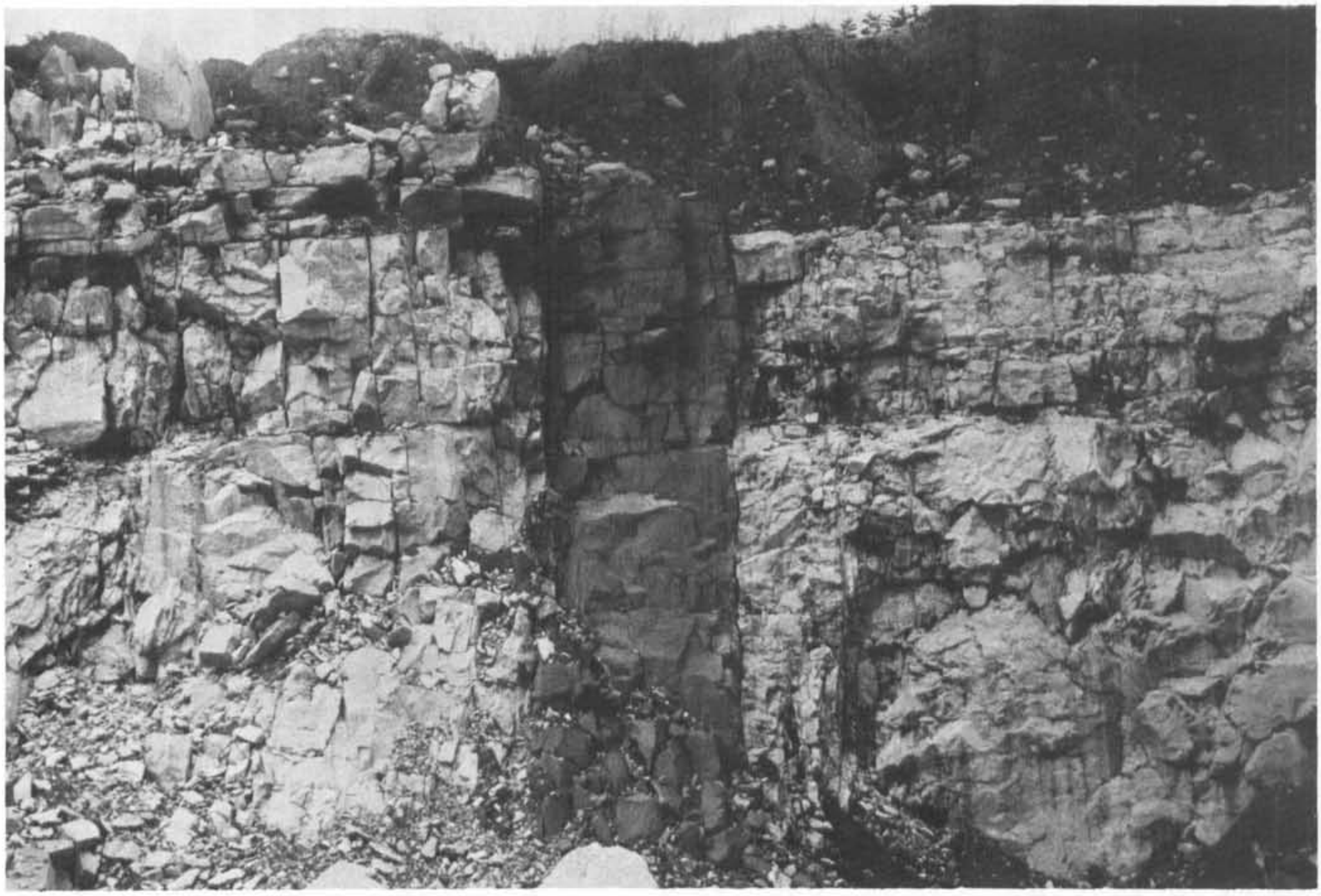

Figure 12. Bostonite dike in limestone marble exposed in a quarry two miles east of Shelburne.

rocks are essentially the same as those of the mountains but the rocks differ because they have different geologic histories.

Quartzite is a metamorphic equivalent of sandstone that has been changed to the degree that recrystallization of the quartz (silica) has occurred but no new minerals have formed. The rock, therefore, is composed predominantly of quartz that makes it massive, hard and quite resistant to both physical and chemical weathering and erosion.

Limestone marble (designated limestone on the bedrock map) is recrystallized limestone. In the Burlington-Middlebury region these rocks are fairly coarse grained at the southern border but they grade into fine textures to the north. Because of the fineness of the grain, geologists are prone to refer to the rocks in the northern two-thirds of the region as simply limestone. These have, however, undergone some recrystallization and can correctly be classified as marble. Limestone marble is composed predominantly of calcium carbonate (calcite) and is therefore quite susceptible to chemical weathering. Acidic waters dissolved the carbonate forming rills on the surface and enlarged the fractures in the rock (Figure 13). Limestone marble is a fairly soft rock and is also readily weathered and eroded by physical processes.

Dolomitic marble (designated dolomite on the bedrock map) differs from limestone in that it is composed predominantly of the mineral dolomite, a carbonate containing about equal amounts of calcium and magnesium. The appearance of dolomitic marble is essentially the same as limestone marble. The addition of magnesium to its composition, however, makes the rock harder and more resistant to physical weathering and less susceptible to chemical attack. It is, none the less, slowly dissolved by acid waters and solution weathering does take place causing conspicuous enlargement of the fractures in the rock (Figure 14).

Shale or slate is limited in its areal extent in the Burlington-Middlebury region to a narrow strip along Lake Champlain, mostly in the Willsboro and Port Henry quadrangles. Shale and slate are very fine-textured rocks that are relatively soft and easily eroded by physical processes. The rocks are generally fractured and the fracture zones are the first to be attacked.

Many of the rock layers of the Champlain Lowlands are composed of two or more combinations of

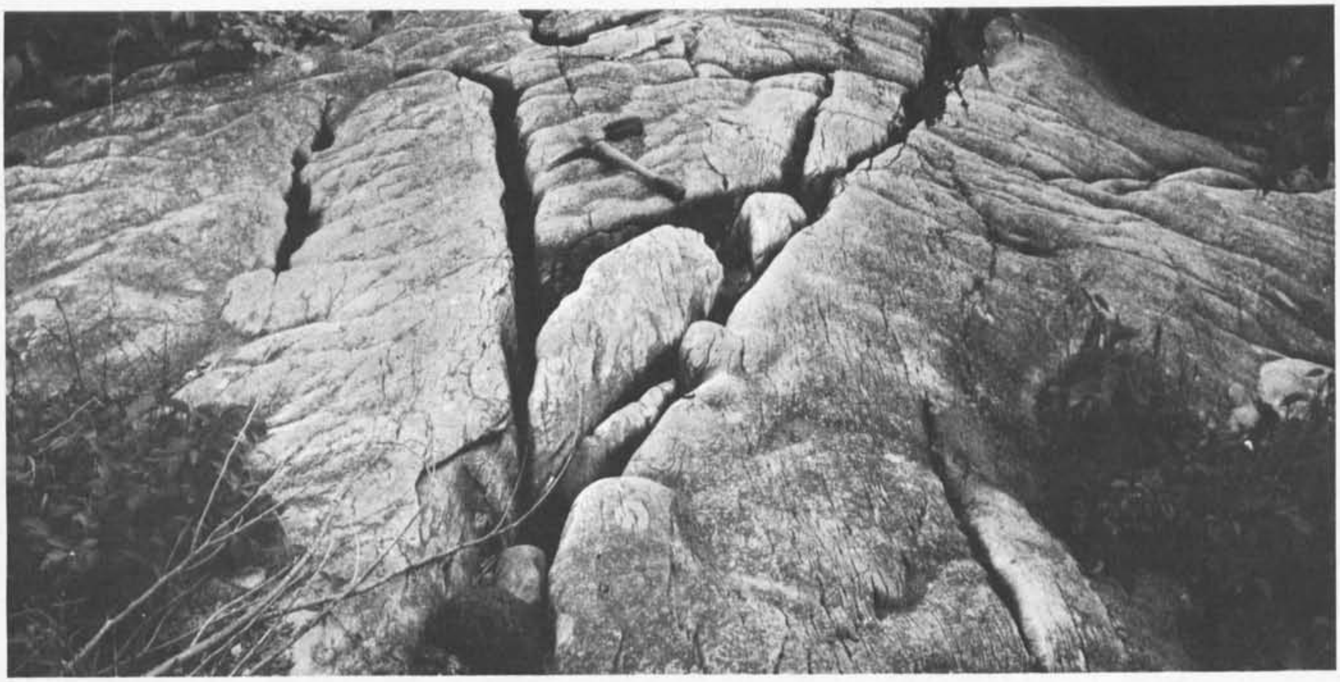

Figure 13. Solution weathering of limestone marble two miles east of Shelburne.

Figure 14. Fracture in dolomite marble enlarged by solution weathering. Three and one-half miles north of Bristol.

the above lithologies (Plate II). The physical and chemical properties of the combined rock types are determined by the relative amounts of each kind of rock. The quartzite with interbedded dolomite, for example, is predominantly quartzite with subordinate amounts of dolomite and is therefore quite resistant in most localities. The proportion of each type of rock varies from place to place in a single layer and study of the rock is necessary to ascertain its composition at any particular place.

Because of their resistance to erosion, quartzite and quartzite with interbedded dolomite form the crests of most of the hills and low mountains of the lowland. Hogback and South Mountains, for example, are capped by quartzite, whereas Snake, Buck and Pease Mountains are composed of quartzite and dolomite.

Rocks of the Green Mountains

According to Christman (1961, p. 45) the rocks of the Camels Hump Quadrangle are all of the greenschist facies which means that they are foliated and that the common minerals are quartz, albite, muscovite, epidote, chlorite, and biolite. It is assumed, says Christman, that the metamorphism of the rocks was due to regional stresses since the more intense metamorphic zones are parallel to the Green Mountain anticlinorium. The complex compositions of the rocks is chiefly the result of new minerals that were formed during metamorphism. Most of the rocks are foliated because of recrystallization, forming platy and elongate minerals, and movement along the bedding planes aligned the platy and elongate minerals parallel to the bedding. Geologists refer to this as a bedding schistosity and the alignment of the platy and elongate minerals into layers is called foliation.

Schistose greywacke is a complex, foliated rock formed from an original sedimentary sandstone containing a moderate amount of dark minerals. It now, due to metamorphism, contains several metamorphic minerals, mostly dark colored, that are susceptible to chemical weathering. The dark, chemically dissolved minerals are disseminated throughout the rock and therefore chemical weathering is not concentrated along fractures as in the marbles. These rocks vary from light to dark grey in color.

The remainder of the rocks are mixtures of varying proportions of phyllite, schist, gneiss, greenstone, and amphibolite. The chief difference among these rocks is the degree of metamorphism, the texture and the foliation. Phyllite is very fine textured and is finely foliated, whereas gneiss is coarse textured and has thicker foliation. Schist is intermediate in texture and foliation. Amphibolite is composed mostly of the mineral amphibole, a dark green mineral that occurs in elongate crystals. Greenstone has a green color because of its high content of the mineral chlorite. The chlorite was formed by the alteration of other minerals during regional metamorphism. In general, these rocks have similar appearances and are difficult to distinguish by visual inspection. The rocks also have similar characteristics insofar as their reactions to weathering and erosion are concerned. For this reason, they are all designated with a single color on the bedrock map and the variations are indicated by letter symbols (Plate II).

SURFICIAL MATERIAL

The surficial materials of the Burlington-Middlebury region (Plate I) are composed of transported sediments deposited during and immediately following the last glacial stage of the Great Ice Age. These include detritus deposited directly from glacial ice, sediment formed by meltwater streams, sediment deposited in lakes associated with waning glaciation and marine deposits of a sea invasion into the Champlain basin after the glacier had receded. The surficial materials were laid down during two different ice episodes, the younger Burlington and Shelburne stades of the Wisconsin Stage (Stewart and MacClintock, 1969, p. 56).

One such material, till, is deposited directly from melting ice and is therefore unsorted and contains a wide variety of particle sizes ranging from clay through large boulders. In the Burlington-Middlebury region, the till blankets the uplands as a thin, discontinuous veneer generally less than 10 feet thick. Till with greater thickness is often found in the valleys. Till does not cover the Champlain Lowland below elevations of 700 feet since the receding margin of the glacier stood in Lake Vermont and the ice calved (broke off) into the lake. The lake sediment of the lowland is strewn with cobbles and boulders from melting icebergs formed by the breaking off ice. The tills of this region vary greatly in composition than do average tills. Because tills are unsorted and contain all particle sizes they have low permeability. In this region, however, the high sand content of most of the tills increases the permeability to the point that they can transmit liquids at a slow rate.

Outwash is deposited by meltwater streams flowing from melting ice. These deposits are therefore stratified and have a high degree of sorting. Outwash has a high porosity and permeability and is a very good water-bearing material (aquifer). Kame terraces are outwash deposits formed along valley walls or along the slopes of mountains. These deposits were made in contact with ice and they can usually be identified by the slumping structures which formed when the ice supporting them melted. Kames are rounded hills of outwash that were also deposited in contact with ice. Outwash gravel deposited in a stream valley by meltwater streams is called a valley train and these are horizontally bedded. Outwash deposits are scattered all over the Burlington-Middlebury region.

Lacustrine (lake) and marine sands and gravels, including beach gravel (Figure 15) and deltas, are shallow water deposits that are usually well sorted, although sorting is not as complete as in outwash. In the Burlington-Middlebury region, the marine deposits are restricted to a zone along the lake shore with the highest deposits rising from elevations of about 200 feet at the southern border of the region to 350 feet at Burlington. The sands and gravels have a medium to high permeability depending on the degree of sorting and the amount of silt contained in them. Gravel is generally much thinner than sand and both commonly occur above silts and clays. The water-bearing characteristics of the sands and gravels are controlled by the thickeness of the deposit, the texture, the degree of sorting, as well as the kind of underlying material.

Lacustrine and marine silts and clays are fine textured bottom sediments. They may have a relatively high porosity and be capable of holding large amounts of water, but the permeability of these ma-

Figure 15. Lacustrine beach gravel exposed in a pit one mile southeast of Waitsfield.

terials is quite low with a correspondingly low water yield. Lake and marine clays are not satisfactory foundation materials because they have poor internal drainage and high plasticity. The lacustrine silts and clays in the Burlington-Middlebury region contain cobbles and boulders (erratics) that were strewn over the area by floating ice, as mentioned above. The concentration of these erratics is surprisingly high, particularly in the Burlington section and boulders lining the fence rows, as in till areas, are common.

Recent alluvium is post-glacial sediment deposited by streams. Alluvium generally forms a layer across the valley floors ranging from 5 to 25 feet in thickness. It is a poor foundation material that must be removed for heavy construction. The alluvium also indicates, as a general rule, areas that are susceptible to season flooding.

Peat and muck designate swampy, poorly drained areas. Most of these are small swamps filling shallow depressions with little or no peat. Otter Creek and Dead Creek, a tributary of Otter Creek, contain large areas of swampland on their valley floors. There are also swamps adjacent to some of the lakes and ponds. Some of these swamps may be deep and contain accumulations of peat.

SURFACE WATER

The surface water potential of the Burlington-Middlebury region is relatively high. The possible sources of surface water that are presently available, and should be inventoried, include Lake Champlain, the headwaters of mountain streams, certain lakes and ponds, and a few abandoned stone quarries. Inasmuch as the future water supply of the region may be limited if precautions are not taken, a detailed study of the surface water sources needs to be made; certain areas should be designated water reserves, and these could be set aside for future use. This is one of the most important prerequisites to environmental planning. Residential development, both seasonal and permanent, has already begun in the mountains and along the lake shores and how long it will be until land utilization will have progressed beyond the point where water reserves are possible is not known.

Lake Champlain is the largest potential source of surface water in Vermont. It is, of course, already used and a new water system, using the lake, is now being developed in the Burlington-Middlebury region. The lake, however, has been receiving pollutants from industrial waste and municipal sewage systems for many years. Fortunately, there is much interest at the present time, by both governmental and citizen groups, in cleaning up the lake waters. Renovation and expansion of public sewage systems, however, take tax dollars and this is always a problem with which it is difficult to reckon. It is imperative, none the less, that new water standards be adopted for the lake, and that new, more rigorous, regulations be enacted to control the dumping of industrial contaminants, domestic sewage, and municipal wastes. The water reserve in the lake, if pollution can be regulated, is almost unlimited and undoubtedly there will be an ever increasing demand for water in the region adjacent to it.

The second most important potential source for surface water in the region is from the headwaters of stream systems that rise in the higher elevations of the Green Mountains. As has already been noted, many of the major streams, the Mad, Huntington, New Haven and Lee rivers, head on the high slopes of the mountains. In addition, there are numerous small tributaries with discharges of sufficient volume to be used for a water supply because their origins are in the unpopulated, mountainous terrain. It is the thesis of this report that the most desirable of these streams should be designated water reserves in order to protect them for future use by controlling the development along their courses. There is, at the present time, a minimum of restrictions to any kind of development in almost any section and pollution of these headwaters is almost a foregone conclusion without regulation.

There are a few small lakes and ponds in the region that could be surface water sources if precautions are taken to protect them from pollution. These lakes and ponds are located on the lowland and include Lake Iroquois and Bristol, Monkton and Shelburne ponds. These are small bodies of water, but each of them is capable of supplying a steady flow over a long period of time.

It was suggested in the report on the Rutland-Brandon region that many of the water-filled, abandoned stone quarries might be used as a water source (Stewart, 1972, p. 19-20). There are only a few such quarries in the Burlington-Middlebury region, but those that do exist are possible water sources.

GROUND WATER

The data collected during this study pertaining to the ground water supply was accumulated from several different sources. The basic and most useful information was taken from water-well records on file at the Vermont Department of Water Resources that have been required of all drillers since 1966. These records supply information that assists in the determination of certain geologic conditions such as the type and thickness of the material above bedrock, the depth of each well, the amount of water produced at each location, the depth to bedrock, and the location and depth of buried valleys. These records are on open file and are available to planning agencies.

Thirteen localities were selected for seismic study where well-log and field data indicated good water potential. The seismic results give information concerning ground water in that it gives the width, depth, and shape of a stream valley, the location of buried valleys, the depth to saturated surficial material, and a generalized profile of the sedimentary layers above bedrock. In the Burlington-Middlebury region, seismic studies were chiefly for the purpose of ascertaining significant characteristics of the unconsolidated sediment in stream valleys. Seismic data alone allow materials to be classified into broad groups based on the velocities of the seismic wave transmitted through them. Each velocity does not, however, have a unique material classification, but most bedrock and surface material have a definite velocity range.

Bedrock has a high seismic velocity, generally above 12,000 feet/second because of its density. The seismic velocities of unconsolidated sediment are much lower. Dense, saturated till commonly has a velocity range between 3,500 and 4,000 feet/second but compact, dense till may have velocities as high as 8,000 feet/second. Alluvium, stream sediment on valley floors, has seismic velocities ranging between 800 and 2,000 feet/second. Unconsolidated sediment that is saturated with water usually has a seismic velocity between 4,000 and 5,500 feet/second. Ground water in quantities great enough for a municipal water supply has been restricted to material with velocities between 4,800 and 5,300 feet/second. Material with velocities greater than 5,300 are too dense and compact and have permeabilities that are too low to yield large quantities of water. Material with velocities below 4,800 are usually not saturated (Weston Geophysical Engineers, Inc., 1972). The seismic profiles reproduced in this report were made by Weston Geophysical Engineers, Inc., during this study. The exact location of each seismic profile is shown on the maps in Appendix A.

The *Ground Water Favorability Map* (Hodges, 1967, Hodges and Butterfield, 1967 and 1968) of each stream system was used to ascertain the available ground water data at the time of its publication. These maps show all of the significant ground water information and the most favorable sections for ground water occurrence known at that time. They also contain statistics about wells with high yield. Highway Department drill-holes are also located and described. It is not the intention of this report to supersede the favorability maps with the *Ground Water Potential Map* of this report. The favorability maps are accurate and have supplied much data for this study. The ground water map of this report

(Plate II) brings the ground water data up to date by utilizing well logs, geologic information and seismic data.

Ground water is definitely a limited resource in the Burlington-Middlebury region and its study and management poses one of the most important aspects of environmental planning. As stated earlier, a surface water reserve still exists, but regulations and probably legislation will be necessary to prevent its pollution. It will be necessary, if the surface water reserves are to be protected, to clean and regulate discharge into Lake Champlain, plan the development of mountain watersheds, and restrict the use of small lakes and ponds. In the event these precautions are not taken, or if taken and prove unsuccessful, then ground water will be the most readily available water resource.

The investigations made during this survey indicate four modes of occurrence of ground water in the region. These are: 1) in zones of intense faulting; 2) in fractures other than faults in the bedrock; 3) in solution cavities and enlarged fractures of the limestones and dolomites; and 4) in the unconsolidated sediment in stream valleys. Of the four occurrences, the unconsolidated sediment in stream valleys seems to offer the largest reserves and can be produced at the least expense.

The areas designated y-2 on the *Ground Water Potential Map* are zones of closely spaced, intricate faulting that are believed to have moderate to high ground water potential (Plate II). The designation of these sections is made with two important reservations. In the first place, the details of the faulting in this region have not been mapped, except in a section adjacent to Lake Champlain that was surveyed by Welby (1961). Undoubtedly there are other areas on the Champlain Lowland and in the Green Mountains that are as intensely faulted as the strip mapped by Welby. A section high in the Green Mountains two miles east of Appalachian Gap, for example, is believed to be a fault zone because two wells at that location yield 1000 and 300 gallons of water per minute. The average yield of the wells in this area is 4 to 15 gallons per minute and 50 gallons is considered very high. Regardless of other areas that may have fault zones, it was deemed advisable to separately designate the sections that have been mapped. A second reservation concerning the fault zones is the fact that there is no documentary evidence that they do actually contain water or that the water yield from fault zones is different from other types of fractures. Since 1966, when well records were required, there have been very few wells drilled in the sections containing mapped fault zones. The wells that have been drilled do not yield water in quantities different from other areas and there is no way to ascertain that the wells do intersect faults. Until such a time when wells are located using geological data to drill into the faulted strata, evaluation of the zones as water-bearing structures will have to remain a matter of conjecture.

There is no doubt that ground water is available in the fractures in the bedrock. Since, as has already been noted, the rocks have been metamorphosed and recrystallized they contain little or no pore space between the grains that would allow the rock to hold water or through which the water could readily move. It is therefore apparent that the rocks, particularly those in the Green Mountains, would yield no water if they were not broken and fractured. The fractures are open at the surface but their width decreases downward so that at depths of 300 to 400 feet most of them are so tight that they do not contain water or the water is held by capillary action. Fortunately the fractures trend in all directions and intersect at depth and for this reason, the water is usually under hydrostatic pressure and commonly rises in the well. Bedrock water wells producing from fractures, as a general rule, have a very low yield, ranging between 2 and 15 gallons of water per minute with a few wells producing as high as 50 or 60 gallons per minute. Inasmuch as the uplands of the Burlington-Middlebury region have bedrock exposed at the surface or a thin mantle of low permeability till covering the bedrock, the fractures in the bedrock are the only source of water. The Champlain Lowland in many areas is covered with low permeability silts and clays and other sections are barren of sedimentary cover and in these areas bedrock is also the only available source of water.

The limestone and dolomitic marble of the Champlain Lowland is highly fractured as are the other kinds of rock. In the case of the carbonate rock, however, the fractures have been significantly enlarged by solution weathering. The enlarged fractures and cavernous channelways in the rock (Figures 13 and 14) act as avenues for the downward movement of water and form openings in which the water can be stored. There is very little data available on the actual production of water from solution cavities in the Burlington-Middlebury region. Well records, which do give water yield, do not show conspicuous differences in water production between those rocks which are soluble in acid waters and those that are not. It was noted in the report on the Rutland-Brandon region (Stewart, 1972, p. 22) that wells located in dolomite and limestone by the Vermont Marble Company geologist did have significantly higher yields. There is a definite need for additional research on this aspect of water availability in Vermont. Tests made in Pennsylvania by Lattman and Parizek (1964, p. 82-83) indicate greatly increased yield in fracture zones of carbonate rock. To the writer's knowledge, there have been no attempts in this region to purposely drill for water in the solution cavities or the enlarged fractures of the limestone or dolomite. The water that occurs in fractures and solution cavities in the rock is most susceptible to contamination. Whereas organic contamination in water would be removed in a short distance by filtration through sand or other sediment, it might travel for miles through rock fractures or solution cavities without removal (Hodges, 1967). Once contamination occurs, control and abatement are very difficult.

The best possibilities for ground water in the Burlington-Middlebury region are from unconsolidated sediment in the stream valleys. This is also the environment about which there is the greatest amount of information. As a general rule, the water wells with the highest yields are those that produce from gravels and sands in the valleys. The seismic investigations made during this study produced additional data concerning the water potential of these areas.

The Winooski River valley probably has the most favorable ground water potential of any valley in the region. Except for a few sections where bedrock forms the stream channel and the clay-filled valley west of the Winooski Gorge, there seems to be good evidence for water all along the river's course. At Waterbury, where the river enters the region, the present river channel apparently does not follow the deepest part of the valley. At the east end of the village, the deepest part of the buried valley is to the south (Stewart, 1971, Figure 12) but in the middle of the village the deepest channel is to the north of U.S. Route 2 (Figure 16). The buried valley varies in depth between 50 and 150 feet to bedrock from Waterbury to Bolton Falls where the former channel lies to the south of the present river's course (Stewart, 1970, Figure 7). The town of Waterbury has a well in the northwest part of the village that yields 300 gallons of water per minute from gravel at a depth of 140 feet (Hodges and Butterfield, 1967).

West of Bolton Falls, in a two-mile stretch of the river, the valley is too shallow to have a high water potential, but the valley widens again east of Bolton Village and has indications of a good water potential extending to the vicinity of Essex Junction. Well records indicate the fill in the valley between Bolton and Richmond is deep with the water wells penetrating gravel to depths of 50 to 125 feet and yields generally between 5 and 75 gallons per minute. One well in Richmond village reportedly produces 140 gallons per minute and another 200 gallons per minute at depths of 42 and 33 feet respectively. The valley northwest of Richmond seems to be the most favorable section of the river for water. Two and one-half miles northwest of Richmond the Winooski Valley is over a mile wide and seismic investigations indicate a maximum depth of 240 feet (Figure 17). It is believed that the valley fill at this location is sand and gravel inasmuch as Highway Department borings immediately to the southeast show sand and gravel at depths of over 80 feet. At North Williston, two and one-half miles to the north, seismic work shows the fill in the valley is 125 feet deep (Figure 18). There are no available well records for this section of the valley between Richmond and North Williston but there definitely is a high ground water potential, probably the highest in the Burlington-Middlebury region. Southeast and south of Essex Junction the Winooski Valley, according to well records, is filled with lake and marine silts and clays or till and therefore a low ground water potential. But between the falls at Essex Junction and the gorge at Winooski the valley widens and is apparently filled with sand and gravel. West of the Winooski Gorge the valley is filled with lake bottom sediment, mostly clay (Plate III).

Two sections of the Mad River in the Lincoln Mountain Quadrangle have good ground water potential (Plate III). The valley in the Warren area does not have a good water potential in spite of the fact that there is a kame terrace deposit there. The well records of that section indicate shallow depth sand and gravel overlying till and fine grained lake sediment. One mile north of Warren, however, the valley fill changes to outwash, probably a valley train deposit, which follows the valley almost to Irasville. There are few well records for this portion of the river, but a seismic profile one and one-half miles south of Irasville shows a steep-sided buried valley with sediment varying from 65 to 75 feet on the sides to 125 feet near the center (Figure 19). Between Irasville and Waitsfield the valley is filled with till,

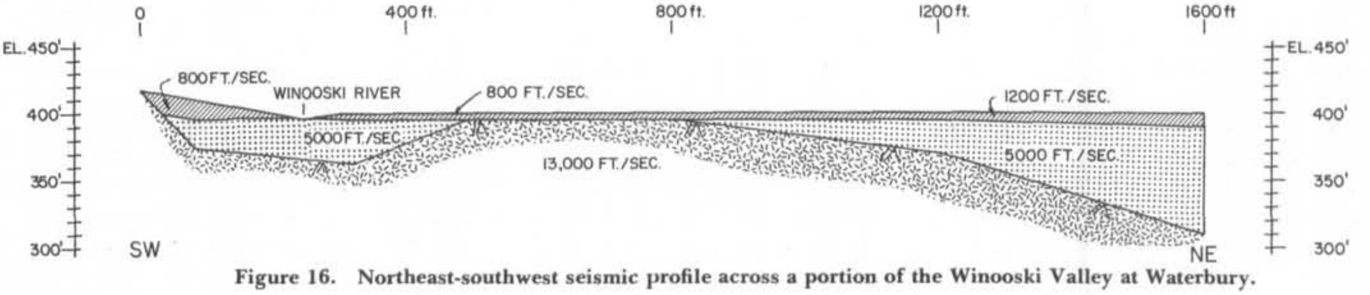

Figure 16. Northeast-southwest seismic profile across a portion of the Winooski Valley at Waterbury.

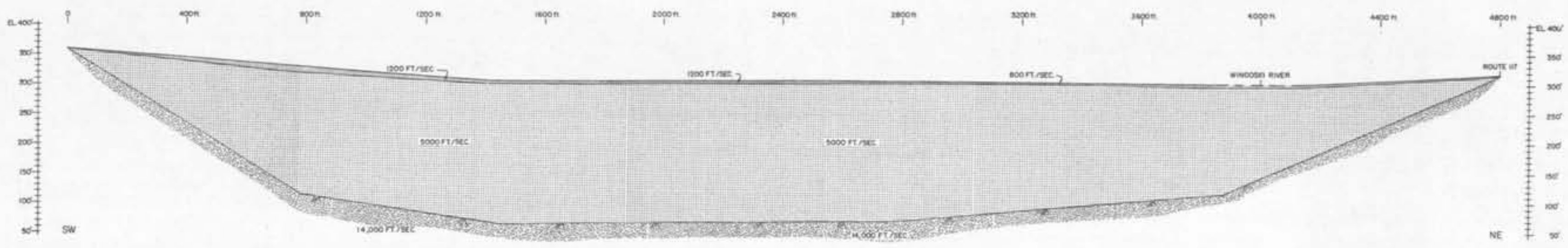

Figure 17. Northeast-southwest seismic profile across the Winooski River valley two and one-half miles northwest of Richmond.

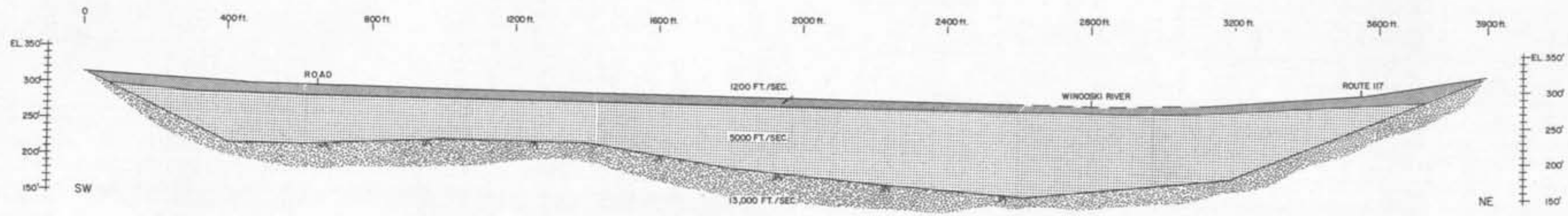

Figure 18. Northeast-southwest seismic profile across the Winooski River valley one-fourth mile east-southeast of North Williston.

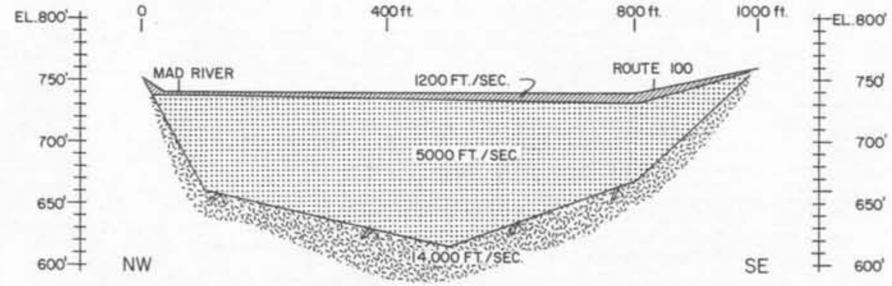

Figure 19. Northwest-southeast seismic profile across the Mad River valley one and one-half miles south of Irasville.

but at Waitsfield and northward to Moretown the valley is wide and seemingly has a high water potential. Well records and seismic investigation indicate 75 to 135 feet of fill in the valley (Figure 20). Downsville Brook, a tributary of the Mad River in the vicinity of Moretown, has a valley filled with 60 to 80 feet of sand and gravel with good water possibilities to the vicinity of South Duxbury.

The Huntington River valley is most interesting insofar as the ground water potential is concerned. Well records are fairly complete for parts of the valley and completely absent for others. Seismic profiles were made across the valley at three different locations and in the vicinity of Huntington Village the profiles and well records suggest different geologic conditions. South of Huntington Center there is only one well record in the valley, but a seismic profile in this section shows 50 to 85 feet of saturated sediment and the well record at this location indicates sand and gravel (Figure 21). The valley north and south of the profile is seemingly filled with finer grained lake sediment. This section, however, should have more detailed study. The headwaters of the Huntington River from the vicinity of Jerusalem north to Huntington Center flows through a valley filled with kame terrace deposits. The water potential of this part of the valley is difficult to ascertain inasmuch as there are no well records except the one described above.

From the vicinity of Huntington Center northward through Huntington Village to the old Towers School, two and one-half miles north of Huntington, the well records suggest a valley fill of sand and gravel varying in depth between 55 and 120 feet. Many wells in this section yield over 50 gallons of water per minute, four produce 100 to 125 gallons per minute, and one over 500. A seismic profile at the north end of this section, near Towers School, shows maximum depth of 120 feet and well records indicate the sediment is sand and gravel (Figure 22). The seismic profile in the village of Huntington shows the maximum depth of the valley to be 105 feet. The lower level of the valley is filled with till with a maximum thickness of 85 feet and the maximum depth of gravel is only 30 feet (Figure 23). There are well logs for seven water-wells in the immediate area of the profile. One well produces 12 gallons of water per minute from gravel at a depth of 120 feet. The six other wells, none of which reach bedrock, penetrate sand and gravel to depths of 55 to 71 feet, and their yields are 100, 60, 100, 50, 500, and 100 gallons per minute. The yield of these wells substantiates the logs inasmuch as their production is too large for till. For these reasons, the ground water map has classified this section as having a high ground water potential (Plate III).

The LaPlatte River valley in the vicinity of Shelburne and Shelburne Falls has a high ground water potential (Plate III). This section has a buried valley that extends for three and one-half miles almost due south from the mouth of the river at Shelburne Bay. The buried valley, as delineated on the ground water map, is not actually the present LaPlatte River valley. The LaPlatte Valley turns east less than one mile south of Shelburne Falls whereas another valley continues southward. It is apparent that there is a preglacial buried valley between Shelburne Bay and Pease Mountain. This and other buried valleys in this area are shown with broken-line boundaries on the *Ground Water Potential Map.* Whether or not the north-south valley was a major stream or a tributary of the pre-glacial LaPlatte is not known. At any rate, the well logs show several wells in the Shelburne Falls section that penetrate sand and gravel to depths of 100 to 165 feet. At the village of Hinesburg, the LaPlatte valley is wide and flat. The town of Hinesburg has wells at Hinesburg Village that penetrate 47 feet of gravel and produce about 100 gallons of water a minute. A seismic profile shows the buried valley to be at least 75 feet deep (Figure 24).

The Lewis Creek valley is filled with till from North Ferrisburg to the vicinity of South Hinesburg and the ground water potential for this section is quite low. From the South Hinesburg area southeastward toward Starksboro, however, lake sediment

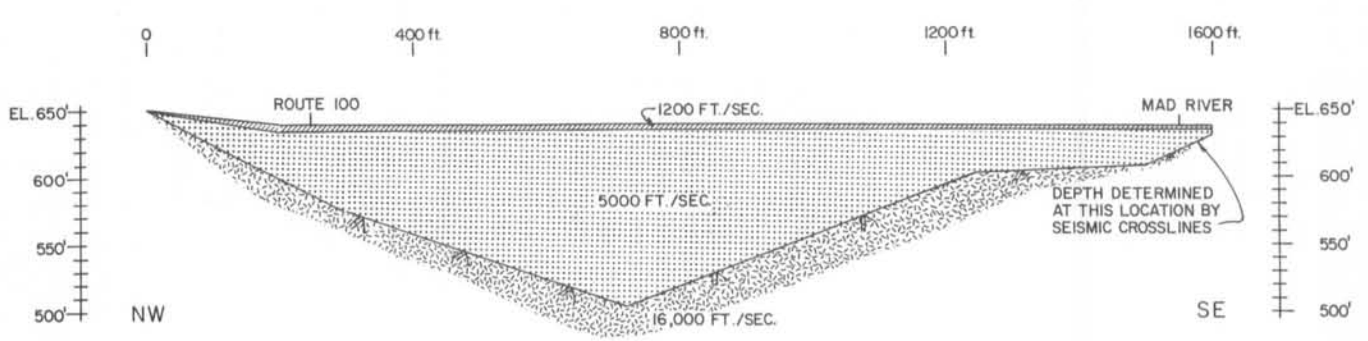

Figure 20. Northwest-southeast seismic profile across the Mad River valley one and one-half miles southwest of Moretown.

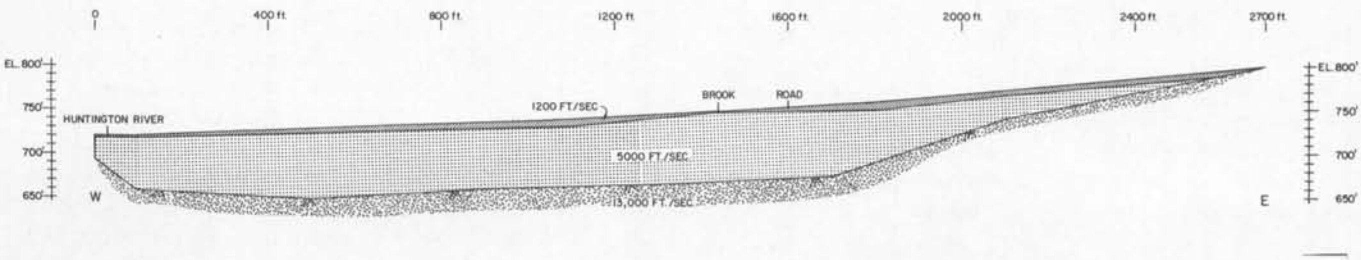

Figure 21. East-West seismic profile across the Huntington River valley one and one-fourth miles south of Huntington Center.

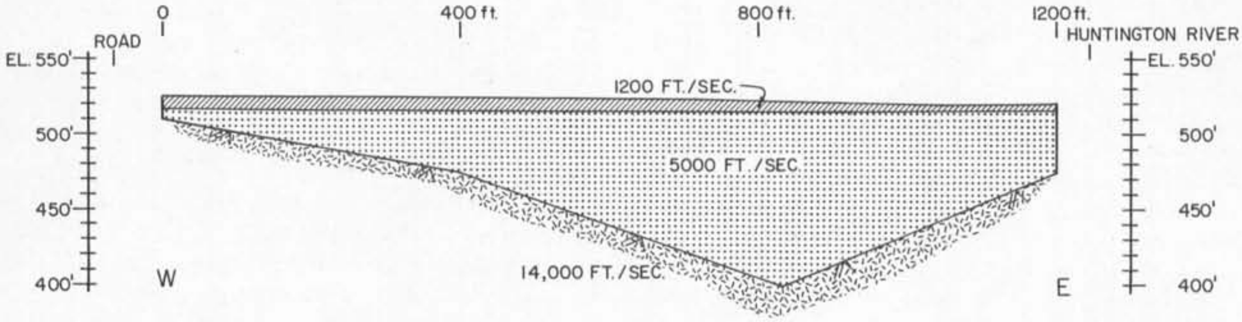

Figure 22. East-West seismic profile across the Huntington River valley two and one-half miles north of Huntington Village.

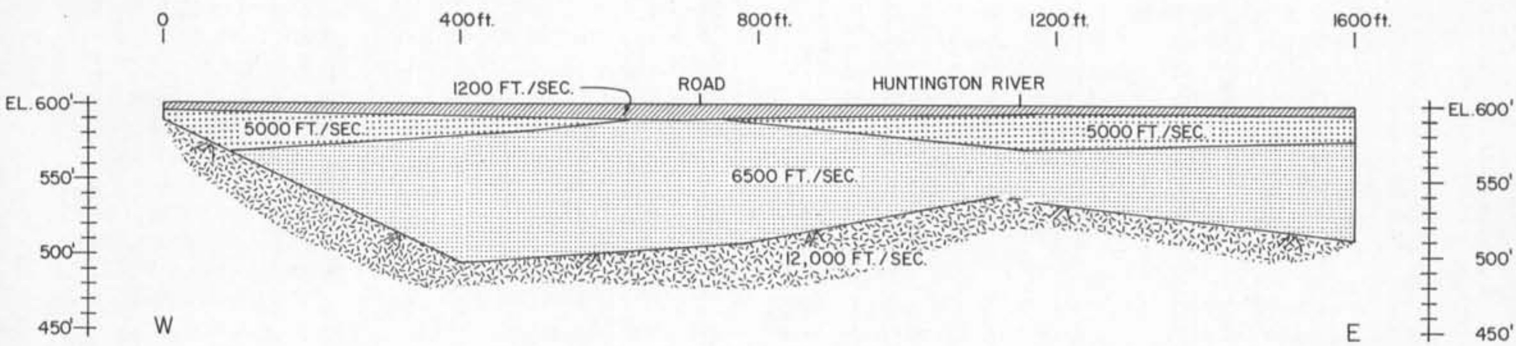

Figure 23. East-West seismic profile across the Huntington River valley in the village of Huntington.

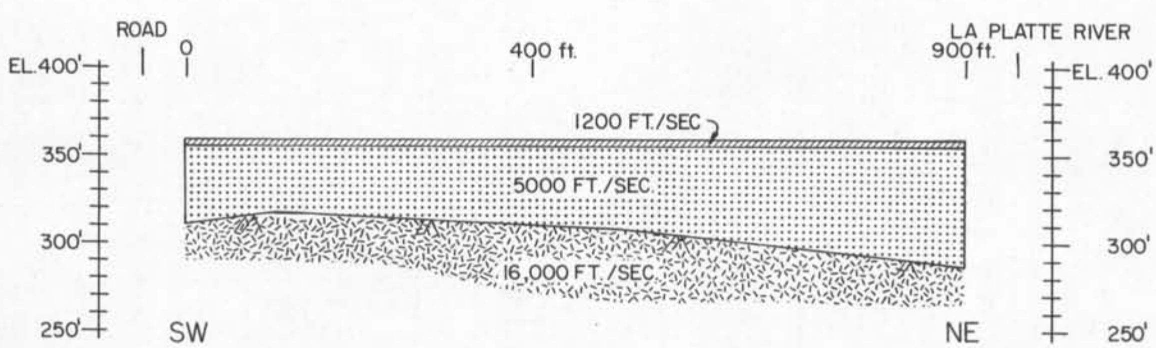

Figure 24. Northeast-southwest seismic profile across the LaPlatte River valley one-fourth mile south of the village of Hinesburg.

of various textures fill the valley. Records are not available for this portion of the valley but it is believed that there are some sectors with water possibilities. In the valley of the headwater stream south of Starksboro, east of Hogback Mountain, Highway Department borings and a seismic profile show a low water potential. Although the buried valley is 155 feet deep where the seismic work was done, sand and gravel have a maximum thickness of 50 feet at the top of the fill and the fill in the bottom of the valley is till with a thickness of as much as 125 feet (Figure 25). The lower reaches of Lewis Creek valley west of North Ferrisburg also have possibilities for water.

Otter Creek valley flows mostly over lake clays and silts with low permeability, except in a few short sectors where bedrock is exposed in the stream channel. Between Middlebury and Weybridge, the water potential is very low, but the remainder of the valley, downstream from Weybridge, may contain appreciable amounts of water in sand and gravel at the bottom or in the bedrock immediately below.

The New Haven River, a tributary of Otter Creek, from a point three miles south of South Lincoln to Ackworth, east of Bristol, flows through a valley filled with kame gravel. This section of the valley is believed to have at least a moderate water potential. There are no well records available for this area and it is probable that ground water possibilities are higher than rated by this study (Plate III). At Bristol the river turns and flows southward through a valley one-half to one mile in width to New Haven Mills. The wide valley is called Bristol Flats and the only well log from this locality shows a buried valley 262 feet deep filled with till above silt. The seismic profile made across the valley one mile south of the well, however, indicates 55 feet of sand and gravel above 85 feet of till (Figure 26). The buried valley is deep and wide, contains a variety of sediments and probably contains some water in the gravel and possibly below the till. Unfortunately, the seismic profile does not reach bedrock except in one 400-foot span and therefore the actual shape of the buried valley is not known. The New Haven Valley narrows at New Haven Mills and widens again one mile to the southwest. A seismic profile across the valley, one and one-half miles southwest of New Haven Mills, shows a maximum of 35 feet of gravel (Figure 27).

Beaver Brook, a tributary of the New Haven River which drains the valley north of Ackworth, flows through a valley with a floor one-fourth to one-half mile wide where surface indications suggest a good water potential. A seismic profile across the valley two miles north of Ackworth, however, shows a variable depth and bedrock almost at the surface in the middle of the valley (Figure 28).

Certain gravel areas, mostly along the western foothills of the Green Mountains, are important ground water sources in the region. A kame terrace follows the base of the mountain from the southern boundary of the Middlebury Quadrangle to Bristol and includes the flat-topped terrace on which Bristol is located. Water wells recently drilled in the terrace vary from 50 feet to 390 feet in depth and none of them reaches bedrock. The yield of these wells ranges from 5 to 85 gallons of water per minute, except for one well located one-half mile from the southern border of the map, that produces 300 gallons per minute. North of Bristol, a kame terrace on the east slope of Hogback Mountain is assumed, on the basis of other kame areas, to have a high water potential although no records are available to substantiate this belief. The kame terrace between Starksboro and South Hinesburg is generally thin and does not seem to have a high ground water potential. The Hinesburg kame terrace, north of South Hinesburg, however, should contain a high reserve of water.

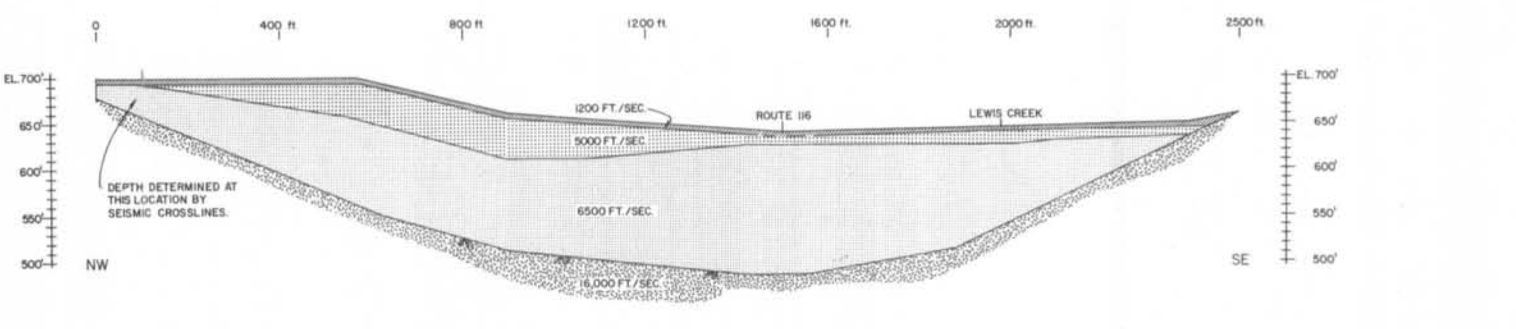

Figure 25. Seismic profile trending southeast-northwest across the Lewis Creek valley two miles south of Starksboro.

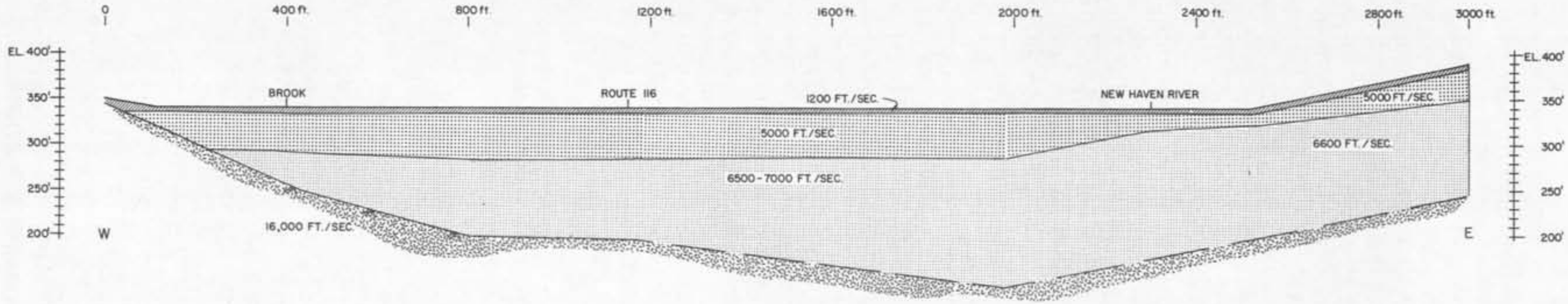

Figure 26. East-west seismic profile across Bristol Flats two miles south-southwest of Bristol.

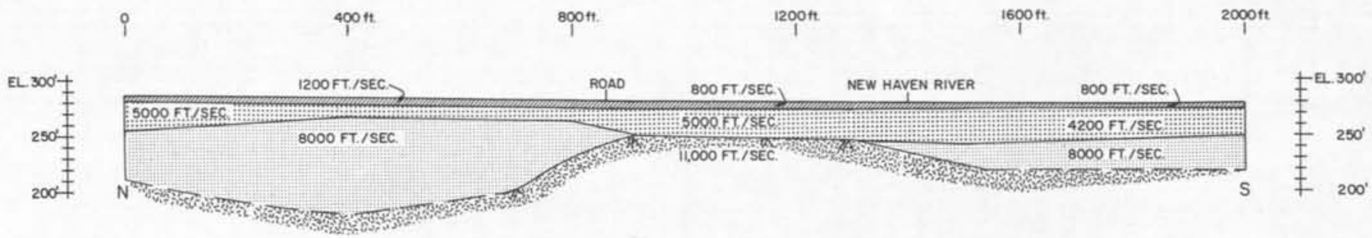

Figure 27. North-south seismic profile across the New Haven River valley one mile southwest of New Haven Mills.

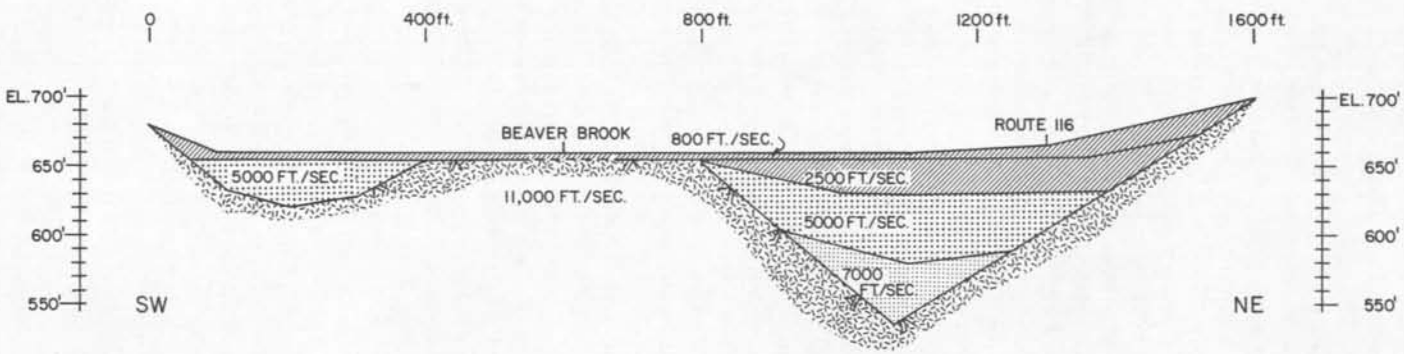

Figure 28. Northeast-southwest seismic profile across Beaver Brook valley two miles north of Ackworth.

SOLID WASTE DISPOSAL

The geologic problems associated with solid waste disposal, particularly the landfill type, are due primarily to the fact that when refuse is saturated with water, even intermittently, it produces a liquid contaminant called leachate. The leachate thus formed usually contains a high concentration of dissolved material. Because the leachate is liquid, it is a transporting agent for both biological and chemical pollutants. For this reason, it is imperative that the solutions do not seep downward to the ground water table, move laterally into surface water or upward to the surface of the ground. In the Burlington-Middlebury region, as already explained, much of the subsurface water is held in fractures in the bedrock and in solution cavities where filtering action is very slow. The important safeguard in this case is to prevent the leachate from entering the fractures in the rock by containing it in surficial material with low permeability above bedrock. In other situations, where water is available in the porous, unconsolidated sands and gravels in stream valleys it is necessary to prevent the leachate from seeping down into the zone of saturation below the water table. Since the materials above the water table in the valleys is usually permeable sand and gravels, the retention of the leachate above the zone of saturation is quite difficult and often impossible.

Recent research concerning the hydrologic implications of solid waste disposal, the work of Hughes, Landon, and Farvolden (1971), for example, shows that the pollution hazards from landfill sites are not as difficult to control as it had formerly been assumed to be. These investigations, however, were not made in regions of fractured bedrock and they do not, therefore, readily apply to the Burlington-Middlebury region or to other sections of Vermont. The recent studies do suggest that, even in some localities where pollution seems to be inevitable, modification of the site so as to satisfactorily contain the leachate is possible at reasonable expense. Modification as used here refers to the use of plastic liners, clay fill, spray seals, etc., that reduce the permeability to a satisfactory level in the immediate vicinity of the landfill. The evaluation of the solid waste conditions in this report (Plate IV), however, is based on potential use without modification.

There are two important precautions that must be taken in the Burlington-Middlebury region to reduce the rate at which leachate is produced and to restrict the movement of leachate formed to a small area above bedrock or above the water table. In the first place, care must be taken in the selection of a site location to make sure that the surficial material is of low permeability and of sufficient thickness to contain the leachate. Of the surficial materials in the region, till is no doubt the most suitable for landfill use since it has a low permeability and is not too compact to excavate. Lake and marine silts and clays are also suitable because of their low permeability, but they are usually more compact and more difficult to remove. The second precaution that is necessary is the use of a nonpermeable material for a cover to prevent surface water from entering.

A proper cover for a solid waste landfill is important for at least three reasons. First, the amount of water entering the landfill determines, in a general way, the rate at which decomposition takes place and therefore the amount of leachate formed. Second, excess water entering the landfill causes the formation of ground water mounds. Such mounds form when water that enters the fill is so restricted in its lateral flow that it builds up in and along the sides of the fill. When the mounds build high enough to intersect the ground surface the leachate flows out as springs along the margins of the fill (Hughes, Landon and Farvolden, 1971). A third reason for an impermeable cover, especially in Vermont, is to prevent the freezing and thawing of water in the refuse during the winter months. Since the material containing the refuse is of low permeability, water that infiltrates will collect and freezing and thawing will occur. Repeated freezing and thawing of water causes frost heaving that would loosen and dislocate the compacted refuse, allowing more water to enter.

The solid waste conditions map of this report (Plate IV) gives a generalized classification as it relates to solid waste landfill suitability. The areas outlined on the maps have been so designated chiefly on the basis of permeability and thickness of the surface material without consideration of the possibilities for modifications. The map is intended as a guide for use in the selection of landfill sites, but it does not assume that detailed study of each individual location will be unnecessary. As a general rule, the hydrologic conditions vary so much from one locality to the next that it is not possible to predict exact characteristics.

The green (g) sections on the map have till or silts and clays covering bedrock with thicknesses in excess of 30 feet. This is the thickness that has been suggested by the Illinois Geological Survey (Cartwright and Sherman, 1969; Hughes, Landon and Farvolden, 1971) as a minimum to assure the containing of the leachate, but the Geological Survey of Alabama recommends a thickness of 50 feet (Ricco and Hyde, 1971). Inasmuch as the surficial material in Vermont is similar to that of Illinois, a thickness of 30 feet seems adequate. Under these conditions landfills can be operated with maximum efficiency using the till or silts and clays for cover.

The yellow (y) areas on the map indicate sections with till or silt and clay with variable or unknown thicknesses. Much of the area so legened can be used for landfill simply by ascertaining that the cover is 30 feet or more in thickness. In localities where the cover is 20 to 30 feet or more in thickness, a landfill site may be developed with a minimum of modification. If the cover is less than 20 feet thick, modification is necessary in sealing the excavation to assure that a minimum of leachate enters the surficial material below the fill.

The areas legened r-2 on the map have permeable sands and gravels at the surface. In some places the sands and gravel extend down to bedrock, but in other localities silts and clays, or possibly till, underlie them. If the sands and gravels are the only material above bedrock the site is usually unsuitable for a landfill inasmuch as it is too difficult to make adequate modifications. If till or silt and clay underlie the sand and gravel and they are over 20 feet thick, the site may be used for landfill only if some type of liner or seal is used to prevent the lateral migration of the leachate. Development of a landfill under these conditions requires detailed study of the site and professional advice in the selection and installation of the seal or liner. Unfortunately, sand and gravel are the most commonly used surficial material for solid waste disposal in the Burlington-Middlebury region. These sites are used without modification chiefly because of the convenience of abandoned gravel pits and the ease with which the material can be excavated and used for cover. For these reasons, over two thirds of the existing landfill operations are located in unsatisfactory sites and it is logical to assume that some of them are, or soon will be, contaminating the local ground water supply. To the writer's knowledge, there are no state or local regulations prohibiting the use of such sites.

The r-1 legend on the map locates swampy and other poorly drained areas. Many of these sections are in stream valleys where seasonal flooding is common. These cannot be used for landfill since it is impossible to prevent pollution of the surface water or the saturation of the landfill.

SEWAGE DISPOSAL

Investigations made during this survey were not particularly concerned with the problems associated with the disposal of liquid wastes from industry or municipalities. These facilities are controlled primarily by rigorous state and federal regulations. The Vermont Department of Water Resources and the former State Conservation Board have, for many years, monitored and maintained a continuous study of the surface water of the state, and staff reports are available on most stream systems. These reports have classified the surface water, noted sources of pollution, and have suggested methods for upgrading the water quality. It suffices for this report to point out that there are still municipalities and industrial installations that do not have adequate disposal systems. Public sentiment generally runs high against any industry that pollutes surface water, but the same public is reluctant to vote levies, increased taxes or bond issues to build, expand, or maintain publicly owned sewage systems. The rules that regulate industry, however, should apply to public sewage systems.

This study is very much concerned with the domestic sewage problems of the Burlington-Middlebury region. As noted earlier, there has been, and no doubt will continue to be, a rapid movement of the population into the rural areas. In these sections, each individual unit must have its own water supply and sewage disposal system. As a result, septic tanks, leaching lines and seepage pits are being installed at an ever increasing rate and projections of future developments indicate a continued demand at an increasingly higher rate.

The septic tank with a leaching field is one of the most reliable sewage disposal systems for rural use. The intermittent flow of waste material in this system is broken down and decomposed by the action of anaerobic bacteria. A properly constructed and installed septic tank causes an anaerobic bacteria treatment, removes the solids from the waste, and stores the sludge and scum produced. The septic tank, however, does not purify the waste or remove the infectious bacteria or the virus. The discharge from the septic tank to the leach line is an odoriferous fluid containing large amounts of anaerobic bacteria, nutrients, salts, suspended solids, and in some cases pathogens.

The function of the leaching field or seepage pit is to dispose of the liquid waste from the septic tank by allowing it to seep into a suitable geologic environment. A series of physical, chemical, and biological activities take place as the liquid from the leach line seeps into and through the surrounding unconsolidated mantle. The soil and unconsolidated surficial material act as a filtering agent, exchange ions with the liquid waste and even act as a bonding agent. Oxidation takes place and aerobic conditions are established. Bacteria in the soil and mantle attack bacteria in the waste material and the temperature is lowered when it contacts the surrounding soil material. (Franks, 1972, p. 195-96). In spite of the importance that has been placed on percolation tests, recent studies have shown that the texture of the unconsolidated surficial material in which the leaching field is located is more important than the permeability (Romero, 1970, p. 44). The permeability of coarse-grained material may thus be too permeable.

The most common test used to ascertain the degree of purification taking place in a leaching field is to determine the amount of coliform present. Coliform is a type of unharmful bacteria that are easy to detect and is an indicator of the presence or absence of harmful bacteria. Experiments have shown that coliform is reduced to undetectable levels after seeping through a few feet of fine sand whereas it may not be lowered to acceptable levels in coarse-textured gravel after over 200 feet of seepage. These data do not seemingly conform to the methods and standards of the U.S. Public Health Service (1967) or the Vermont Agency of Environmental Conservation (1971) which advise percolation tests. The implication of these studies is that coarse sands and gravels are too permeable for use as a filtering material for a leaching field.

It has been determined by recent studies that the flow of contaminants in liquid waste is always in the direction of the natural ground water flow. Unsaturated mantle material is much more effective in the removal of bacteria and virus than saturated. Bacterial pollutants that reach ground water (saturated zone) may travel over 230 feet, but less than 40 feet is necessary for removal in unsaturated fine sand (Franks, 1972, p. 202-03). All of these findings show that, in the selection of a site for a leaching field, factors that should be considered in addition to permeability are the nature of the unconsolidated sediment in contact with the leach lines, the distance of travel in unsaturated material, and the direction of flow from the system.

Another very important factor in the proper operation of a septic tank and reducing pollution is the slope of the surface. Unfortunately it is impossible to take the slope into account when constructing the planning maps inasmuch as the size of the plot of land necessary for a leaching field is too small to show on a map of that scale. Slopes also change too rapidly to be included on a generalized map. Since a large number of the new homesites in the Burlington-Middlebury region are located on hillsides, the effect of the slope on septic tank operation should not be ignored. Septic tank installations on hillside locations are difficult because the unconsolidated material covering bedrock is usually thin and fractured bedrock lies just below the surficial cover. Recent studies have shown that the movement of liquid waste is not parallel to the hillside slope and that the flow of the effluent is eventually toward the surface.

The most hazardous result of septic tank operation in mountainous terrain is the pollution of water supplies. Most homesites in such locations require both a water well and a sewage system and the lot size is often a half-acre or less. Because the cover over the bedrock is usually thin, the effluent from the leach line has only a short flow-distance to reach the fractures in the rock. Liquids passing through fractures, as has already been noted, is not filtered and may move for miles before bacteria and virus are removed. The rock fractures trend in all directions and the location of a septic tank downslope from a well is no assurance that contamination will not occur (Waltz, 1970, p. 42).

A second critical factor relative to the operation of a septic tank on a slope is the inevitable tendency for the effluent to come to the surface downslope from the leaching field or seepage pit. Federal regulations require at least six feet of unconsolidated sediment below the leaching field, but the standard plumbing code suggests that there be at least fifteen feet of horizontal distance between the ground surface and the bottom of the leaching field. According to Franks (1972, p. 201), experience has shown that on slopes exceeding 20% the effluent will probably surface downhill from the system regardless of the type of surficial material or the depth of burial. When such surfacing does occur, the effluent will flow downslope into surface streams. Another very undesirable result of the tendency of the liquid to surface is that it causes saturation of the lower part of the thin surface cover, and the saturated cover creeps, slides or flows downslope. These data strongly suggest that regulations should limit the angle of the slope on which septic tanks with leaching field, seepage pits or dry wells can be constructed.

A so-called mechanical or aerobic tank is one type that might be used in difficult sections of the Burlington-Middlebury region. The mechanical tank, as the name suggests, has an electric motor that is used either to inject air into the system or to activate a stirring mechanism. The major difference between the action in a mechanical tank and a regular septic tank is that the addition of oxygen, usually air under pressure, creates aerobic conditions instead of anaerobic in the mechanical tank. As a result, there is a more complete treatment of the sewage and some systems are said to perform as well as a primary and secondary sewage treatment facility. A decrease in the coliform count has been claimed, but it has never been proven (Goldstein, 1972, p. 39-40).

Because of a more complete treatment of the liquid waste, a mechanical tank can often be used where conditions would not permit the discharge of septic tank liquid. In spite of the better treatment, however, a leaching field is necessary to distribute the waste from the mechanical tank to assure the removal of harmful bacteria and virus. Drawbacks to the mechanical tank are the higher initial cost and the additional maintenance required for the motor and other moving parts.

The septic tank conditions map (Plate V) delineates the characteristics of the surficial material as they relate to domestic sewage systems, particularly septic tanks. The wide use of yellow and red as compared to patches of green suggests that there are few localities that do not have some limitations for septic tank use. The green areas on the map are sections where the till is known to have sufficient thickness and a high sand content and should have a permeability high enough to transmit the liquid from the leaching field. Seepage pits or dry wells are not recommended in till areas since they concentrate the effluent in a smaller area and must be placed at a greater depth where the till is more compact and less permeable.

Most till areas are designated y-1 on the map. The use of septic tanks in these localities is dependent on the thickness of the till above bedrock and the slope of the land. For most efficient operation, there should be 10 to 12 feet of till above bedrock, the land slope should be less than 20 degrees and there should be at least 200 feet of leach line to distribute the effluent.

Areas designated y-2 on the map have permeable sands and gravels at the surface. As noted in the discussion of recent studies pertaining to septic tanks, some of these materials are too permeable and coarse grained to be used for leaching fields. The thickness of the deposit, the depth to bedrock and the occurrence of other kinds of sediment below the sands and gravels are factors that must be considered when planning sewage systems in these areas. Many of the areas designated y-2 are lake and marine sands and gravels that usually have silts and clays below. The finer sediment below will retard the downward percolation of the effluent, if lateral movement is possible without contamination of the adjacent areas.

The areas designated r-1 are low, poorly drained stream bottoms covered with alluvium that may contain swamps. Small isolated swampy areas are also included in this class. The surface material is poorly drained, often wet, frequently flooded and the permeability is generally quite low. Under these conditions, septic tanks would operate only during periods of dry weather.

Areas with a considerable thickness of lake and marine silts and clays are legened r-2 on the map. These areas are so designated because of the extremely low permeability of the silts and clays and septic tanks as they are normally installed will not function properly in such material. Building, of course, will continue in these areas and a special set of specifications for sewage disposal systems in these materials is sorely needed. The mechanical tank with a 200-foot leach line might alleviate some of the problems in these areas. Leach line trenches could be three feet wide with two feet of gravel fill instead of the normal width and depth.

FOUNDATION MATERIAL

Foundations and building conditions in the Burlington-Middlebury region are not as critical as the environmental problems already discussed. Exceptions to this statement include areas of steep slopes in the mountains and areas at the tops and bottoms of clay banks along stream valleys. The criteria for judging the desirability of construction sites include such geologic characteristics as the slope of the land, the internal drainage of the surface material, the plasticity of surficial materials, particularly clay, and the strength of the foundation material. In the region of this study, special planning and some limitations are necessary because of the poor drainage of lake silts and clays and stream alluvium, the plasticity of the clays, the flooding and low strength of the alluvium on stream floodplains, the steep slopes in the mountains and along some valley walls (Plate V).

The floodplains (bottomlands) of most streams are covered with 5 feet to 25 feet of stream-deposited elastic sediment called alluvium. The alluvium is a most undesirable foundation material inasmuch as it is poorly drained, the strength of the material is too low for heavy construction, and flooding, although seasonal, is a serious problem. If the bottomlands are to be used for industrial or other types of heavy construction, the total thickness of the alluvium should be removed and special drainage provided.

Sand and gravel deposits are favorable construction sites since they are well drained, have adequate strength and ground water is usually available in good supply. The economic value of these deposits, however, should be given consideration when such an area is zoned for future use. Good quality gravel reserves should be set aside for use before construction. After the sand and gravel has been removed, most locations still make good construction sites with a minimum of filling and grading. The practice of abandoning gravel pits without reclamation or using them for some kind of a refuse dump is indeed poor planning. These are choice sites for construction. Lacustrine and marine sands and gravels that overlie silts and clays require special study inasmuch as the plasticity of the clay may be too high and slumping, sliding or even flowage may occur. In these cases, the physical characteristics of the underlying sediment must be ascertained as well as the thickness of the sand and gravel.

Lake and marine clays, generally speaking, are often subject to flow inasmuch as they have a high plasticity. In the Burlington-Middlebury region, particularly in the southwestern part, lake clay covers the bedrock and in some sections has a depth of over 100 feet. The internal drainage of the clay is very low which necessitates the inclusion of drainage provisions in all building specifications. Steep slopes in areas of predominantly clay surficial material should be avoided to assure that flows and/or slides do not undermine foundations. Tests to determine bearing strength of the surficial clay as well as tests for plasticity are recommended for each site for heavy construction.

Steep slopes are common along the valley walls of streams, particularly those cut in lake and marine sediment. Slumping, sliding, and creeping are common along these slopes and buildings should not be located on them, near their bases in the valley, or close to the break on top of the slope.

The general construction conditions map (Plate

VI) classifies the surficial material according to its suitability for foundations. The areas shown in green (g) are predominantly sand and gravel deposits. These include lake and marine sands and gravels which may overlie lake or marine silts and clays. Investigations should be made, therefore, to ascertain the depth of the sand and/or gravel and the type of sediment underlying it. The sections designated y-1 are covered predominantly with lake and marine silts and clays. These are often poorly drained. Till sections are legened y-2 on the map and suitable building conditions are dependent upon its thickness. Since the till thickness varies greatly from place to place, building conditions also vary. In most upland areas the till is thin and excavation of the underlying bedrock is often necessary. The bedrock, however, is generally fractured and weathered so that excavation is not difficult. The stream bottomland described above, that is covered with alluvium is designated r-2 on the maps. Red sections marked r-1 are poorly drained, swampy areas that cannot be used for any kind of construction.

GEOLOGIC HAZARDS

The term geologic hazards refers to a variety of destructive phenomena that are directly related to geologic processes. In general, man cannot control or regulate these activities, but he should definitely make allowances for them in his planning. Many of man's activities tend to increase the frequency of occurrence and the amount of damage done by certain phenomena. These hazards include volcanic eruptions that do not occur in Vermont, earthquakes and hurricanes that occasionally occur with minimum effect, and landslides, flash floods and river floods that are potential problems in this region. Planning can facilitate the selective location of industrial installations, municipal facilities and housing developments where the danger from these hazards is minimal.

Landslides

As noted earlier in this report, the lacustrine and marine clays are quite plastic and become slippery when wet. For this reason, landslides are always a threat along steep slopes composed of clay. Quick clay is the name applied to clay masses that may be converted to a viscous liquid and is therefore subject to spontaneous flow. According to Liebling and Kerr (1965), much of the clay deposited in the Champlain Sea, toward the end of the Great Ice Age, has been classified as quick clay. Their report is particularly concerned with the St. Lawrence Lowland, but they report that quick clay has been identified in Vermont. Quick clays are also formed in fresh water and some of the lake clays of the Burlington-Middlebury region may be of this type. At this writing, the identity and location of quick clays in Vermont is a

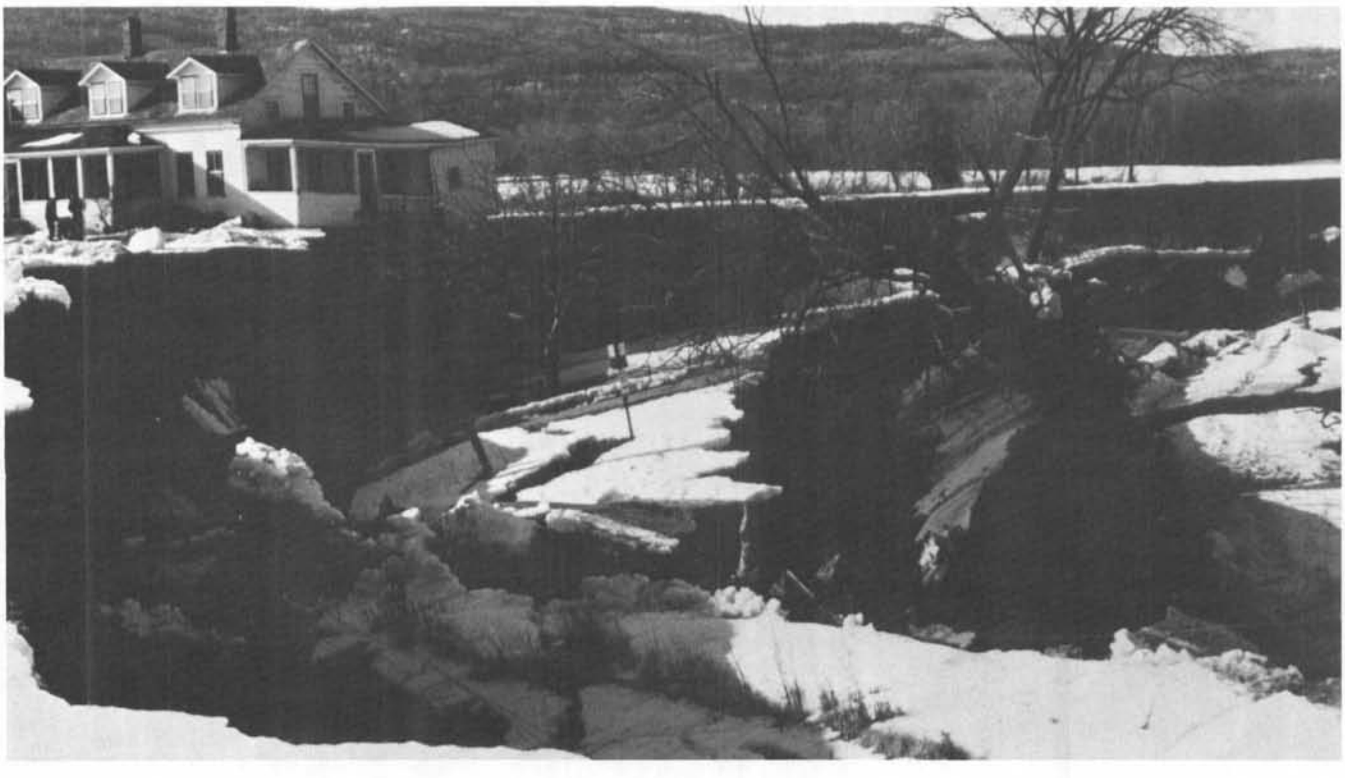

Figure 29. The Weybridge Slide shortly after it occurred in February 1956. Note roadbed and signs at bottom and partially undermined farm home. Photograph by C. G. Doll, State Geologist.

Figure 30. The Weybridge Slide in the summer of 1972. Note foundation of house that had to be moved at upper left.

matter of speculation and until more research is done the potential effect in the region cannot be evaluated.

From the planning point of view, steep, clay slopes should be avoided for any kind of development. Locations above and below the slope should be carefully studied to prevent damage in the event sliding occurs. In the Burlington-Middlebury region, valley walls cut in clay are common along Otter Creek between Middlebury and Vergennes and in some sections of the Winooski Valley between Richmond and Burlington.

One of the largest slides in the region occurred along Otter Creek on February 15, 1956. The location of the slide is one and one-quarter miles southwest of Weybridge and for this reason it is commonly called the Weybridge Slide. This location is along the outside of a sharp bend in the river and in February 1956 the valley walls were steep, almost vertical, due to undercutting by the stream. According to the Addison County Independent (February 16, 1956), the mass of earth dropped 25 to 30 feet and took with it a section of the road (State Route 23) and a motorist en route to work. Electrical power was disrupted and power lines, road signs, and mail boxes were carried down with the slide. A house adjacent to the slide had to be moved and three-fourths of a mile of road relocated at a cost of $50,000 (Figures 29 and 30).

Flash Floods

Flash floods are a common occurrence in the Burlington-Middlebury region, particularly in the Green Mountains. There is much bedrock exposed at the surface in the higher parts of the mountains and most of the water that falls as rain runs off instead of sinking into the ground. During periods of torrential rain, therefore, the water runs down the steep slopes at high velocities and eventually swells the flow of the headwater streams. In times of much flooding, much damage is done to roadways and other developments along the stream courses. In July, 1972, two and one-half inches of rain fell in the mountains during one night and many of the roads were rendered impassable or completely washed away by the following morning (Figure 31).

The mountain streams that are swollen by flash flooding eventually flow into the main drainage of the lowlands. The larger streams are then flooded in a very short period of time. In the region of this study, most of the drainage is into Lake Champlain which is also subject to high water. As earlier stated, the level of Lake Champlain stood three to five feet above normal during the 1972 field season due to an unusually high rate of precipitation.

GEOLOGIC RESOURCES

Although the only geologic resources that are currently being utilized on a commercial scale in the Burlington-Middlebury region are crushed stone and sand and gravel, there seems to be several potentially important mineral materials. Talc, verd antique (the so-called green marble), iron, lime, marble, and kaolin have all been produced at various times in the past and, except for iron, future use of these resources on a commercial scale is indeed probable.

Sand and Gravel

Environmental policies and public sentiment have actually been a hindrance to the development of sand and gravel deposits in the Burlington-Middlebury region in recent years. It seems that the general policy is to keep the landscape as unspoiled as pos-

Figure 31. Road to the Bolton Ski Basin washed out by flash flooding in July, 1972. Two and one-half miles north of Bolton Village.

sible and public sentiment has objected to the unsightly appearance and the dust of the sand and gravel pits. These practices have increased costs of general construction, particularly roads, inasmuch as hauling distances are on the increase even in sections where gravel is available. In the summer of 1972, for example, gravel for a road construction project just south of Vergennes was hauled from New York State in spite of its availability from nearer deposits in Vermont. This report questions the soundness of these policies that seem to restrict the visible but are unconcerned with the unseen. Sound environmental policy promotes the wise use of resources but it does not advocate nonuse on the basis of sightliness.

The sand and gravel map prepared during this survey (Plate VII) classifies the deposits as to quality and estimated reserves. There is no sand and gravel in the region that meets the standard specifications for cement and therefore the highest rank is classified as good. The deposits are scattered over the region but are more concentrated along the western flank of the Green Mountains and in the valleys of the streams. An adequate reserve of both sand and gravel is available for the near future, but the deposits with the largest reserves and highest quality are not located in areas of greatest demand.

The largest reserve of good quality gravel occurs in the Hinesburg area where the gravel terraces were designated the Hinesburg kame terraces by Stewart and MacClintock (1969, p. 125) on the basis of ice-contact structures below surface layers of lacustrine gravel. This classification has been questioned by some who believe that the whole deposit is probably deltaic. Regardless of their origin, the terraces do have a large reserve of gravel that has been the most consistently good grade of any in Vermont. The terraces, located southeast of the village of Hinesburg, are five miles long, average about three-quarters of a mile wide and stand seventy five to two hundred feet above the lowland to the west. Most of the gravel used in the Burlington region comes from these deposits and many other areas also depend on the Hinesburg area for gravel.

The Bristol-East Middlebury kame terraces (Stewart and MacClintock, 1969, p. 137-38) extend from the southern boundary of the region northward to include the flat-topped gravel deposit on which Bristol is built. The terraces which actually extend as far south as East Middlebury are eleven miles long and follow the western base of the Green Mountains. They rise as much as 200 feet above the Champlain Lowland to the west (Calkin, 1965), and the width varies because of the influence of bedrock along the mountain slope. The few pits in the terraces generally show good quality gravel but they are so few that the total reserve is not known.

Large reserves of kame gravel occur on the slopes of the Green Mountains along the headwaters of the Huntington and New Haven Rivers. A deposit that extends for two or three miles north and south of South Lincoln is known to have a large reserve of good gravel. The other sections of these terraces, however, could not be adequately evaluated inasmuch as there were no operating pits where the gravel could be observed intact. A gravel and sand reserve, no doubt of medium to good quality, does exist, but the details are not available.

The sand and gravel reserves of the Mad River valley are predominantly of lake origin. Some of the lake levels in the valley were rather high (up to elevations of 1100 feet) on the valley walls and deltas were built into the lakes (Figure 32). Several of the deltas have been worked out but others have hardly been touched. Exceptions to the deposits of lake origin are the outwash deposits on the floor of the Mad River valley south of Irasville and the kame deposits in the Warren section.

There is a large reserve of sand along the Winooski River valley west of Richmond that also covers a large section east and south of Burlington. The sand deposits were made in the lakes that existed near the end of the Great Ice Age and the Champlain Sea that followed. The sand is mostly deltaic and covers earlier deposits of silt and clay. Since the sand covers lake bottom sediment, it varies greatly from place to place and its maximum thickness has not been determined. Development in this section will no doubt cover most of the sand in the near future, making it unavailable, unless certain areas are reserved for future use.

Crushed Stone

Crushed stone is a valuable resource in the Champlain Lowland but the demand varies with construction needs, particularly for highways. Inasmuch as most of the rock of the lowland can be used for crushed stone, it is common practice to open quarries near the construction site and abandon them as soon as the particular job is completed. Several quarries have been operated along U. S. Route 2 and I-89 in the vicinity of Burlington. In the summer of 1972, however, three quarries, located at Winooski, one mile north of Brooksville and two miles east of Shelburne, were supplying the demand for crushed stone in the whole region. The rocks of the Green Mountains are, as a general rule, not suitable for crushed stone since they contain high percentages of soft minerals such as the micas. The reserve of rock suitable for crushed stone in the lowland is almost inexhaustible, but rock hard enough to pass a Highway Department wear test is difficult to find in the mountains.

Dimension Stone

The Burlington-Middlebury region is north of the Marble Belt inasmuch as the limestone and dolomite marble of the region are generally too fine grained to take a bright polish, a basic requirement for commercial marble. Marble dimension stone, however, has been produced at three different localities in the past. Several abandoned quarries are located along School House Road one and one-half

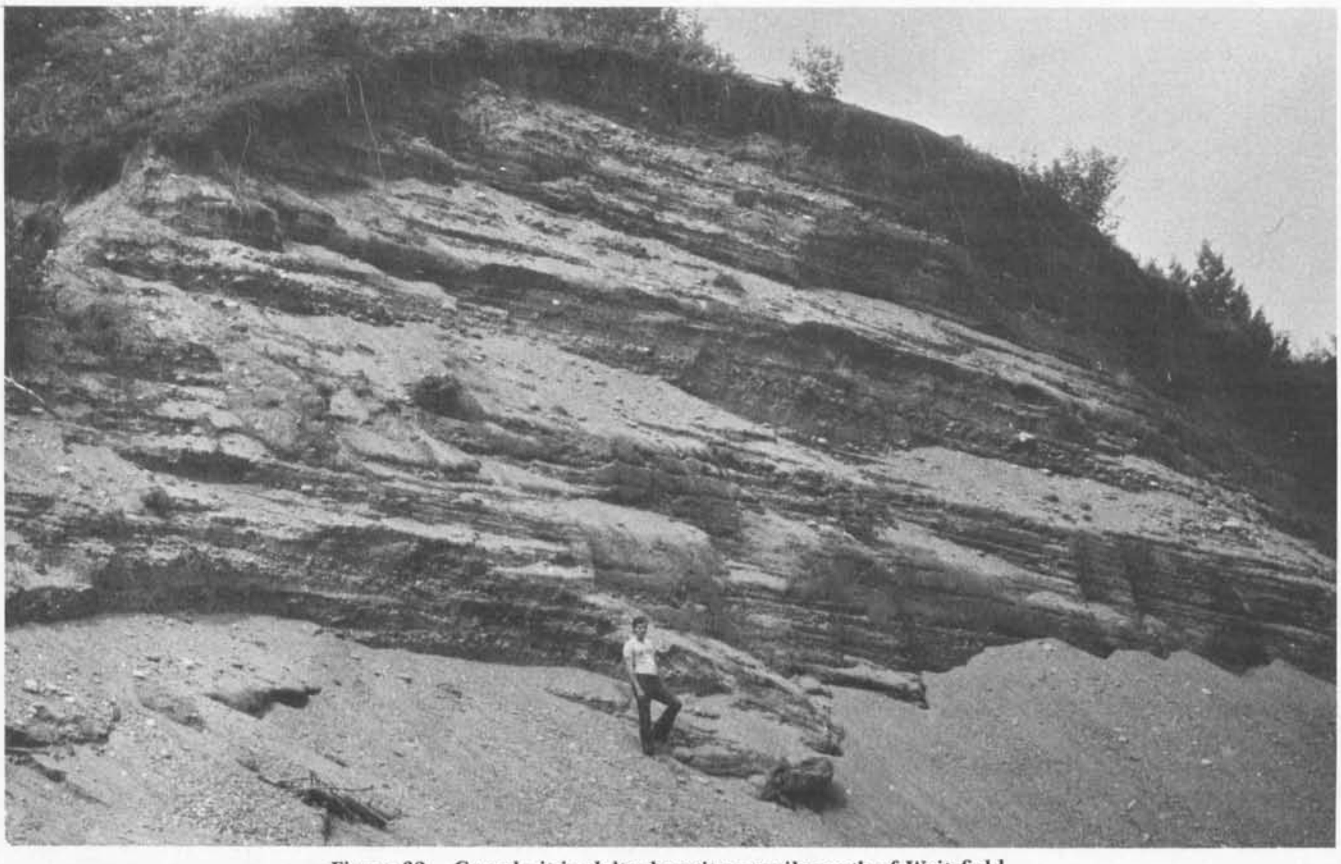

Figure 32. Gravel pit in delta deposit one mile north of Waitsfield.

miles due east of Middlebury. Another abandoned quarry is located along Muddy Branch at the Marble Ledge two miles east-southeast of Brooksville. These two localities were probably quarrying in the same limestone formation. A third locality where carbonate rock has been used for dimension stone lies along the western base of Hogback Mountain three miles southeast of the village of Monkton. Dolomite rock was quarried at this site, but the quarries are much older than those around Middlebury. Red quartzite and sandstone, formerly quarried for dimension stone in the City of Burlington, were used in the construction of buildings and walls on the Redstone Campus of the University of Vermont and many building foundations in the city. One quarry was located just southwest of the Redstone Campus, but other quarries in the same formation are located to the south near Red Rocks Park. Verd antique, the so-called green marble, was quarried years ago at South Duxbury. The quarry, which was recently used for crushed stone for Interstate 89, is located on the hillside one-half mile southwest of the village. The use of the term green marble for this rock is really a misnomer since it is actually a dark colored igneous intrusion that was later metamorphosed. Geologists call these ultra mafic bodies and they contain a variety of minerals depending on the original content of the rock plus the degree of metamorphism.

Talc

The only talc mine that has ever been operated in the Burlington-Middlebury region is located in the same ultra mafic body as the verd antique quarry in South Duxbury described above. The abandoned mine is about one mile south of the quarry and one and one-fourth miles south-southwest of the village. Talc is one of the minerals formed by the metamorphism of the original igneous rock and, according to Grant (1968, p. 36), the north and south ends of this particular body were altered to talc carbonate. The talc mine is located in the south end and the verd antique quarry in the core of the body which was altered to serpentine. There has been much study by private industry in this locality to determine the quantity and quality of the talc reserve.

Lime

Two quite large lime plants in the Burlington-Middlebury region have recently been abandoned. Both plants had operated in the same locality for many years, and both were equipped to produce large quantities of agricultural lime. One of these plants was located at Winooski along the Winooski River immediately east of the Winooski Gorge. Limestone had been quarried from the north and south sides of the river and the processing plant was located on the north valley wall. The second plant was located one and three-fourths miles north of New Haven Junction. Much limestone was produced from these quarries on the east side of Little Otter Creek. The abandoning of these lime plants probably resulted from local problems such as flooding, decreased quality of the rock, and the expense of moving to new locations. It is apparent, however, that there is a large reserve of limestone of the quality needed for agricultural lime in this region.

Figure 33. Pit in Kaolin deposits that was worked by the Vermont Kaolin Corporation 1961-1966. One and one-fourth miles south of East Monkton.

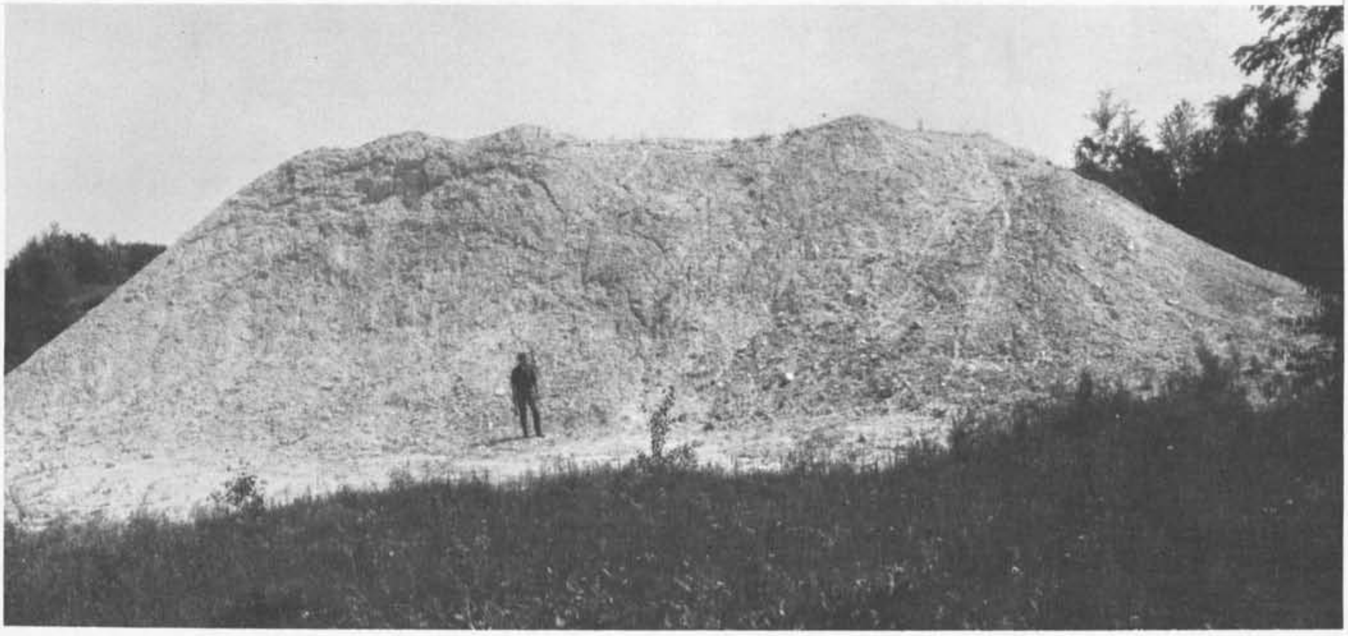

Figure 34. Kaolin stockpiled by the Vermont Kaolin Corporation 1961-1966. One and one-fourth miles south of East Monkton.

Kaolin

One of the most recent mineral operations in the region was a kaolin pit and processing plant operated by the Vermont Kaolin Corporation one and one-fourth miles south of East Monkton (Figure 33). According to Ogden (1969, p. 16), these deposits have been worked periodically since 1792 and have been used for various purposes including crockery, pottery, furnace linings and paper manufacturing. In 1961, the Vermont Kaolin Corporation started operations with a new processing plant and storage facilities with a capacity of approximately 100 tons a day. The plant operated until 1966 and 9,235 tons of clay were produced, but the dry process produced clay that was not of high enough quality for the paper or the ceramic industry (Figure 34). The ore body at this locality is definitely known to be of commercial size and quality (Wark, 1968, and Ogden, 1969), but future operations may need to include high silica sand and aluminum oxide as by-products.

The kaolin deposit is geologically interesting since it is not associated with rocks containing the mineral feldspar from which the clays could have formed as weathering products. Instead, the kaolin occurs in fracture zones and was probably deposited by hot water solution from magmatic sources. The Bristol Ore Beds from which iron was obtained prior to the discovery of kaolin, are associated with the kaolin deposits and probably have a similar origin. The high-grade iron ore minerals hematite and goethite are found here, but they are not in sufficient quantity to be of economic importance.

ACKNOWLEDGEMENTS

Dr. Charles G. Doll, the Vermont State Geologist, directed and arranged the financing of the investigations that produced this report. The writer appreciates his continued support, assistance, and encouragement. Terry M. Kramer and Alan Egler were field assistants and contributed much to the summer's work. They did the drafting for the planning maps. Kramer was responsible for the bedrock maps and Egler collected much of the water data and drafted the maps appearing in the text. The writer also notes the assistance of Mr. Frank Lanza, Geologist, Vermont Highway Department, Mr. Arthur Hodges, Geologist, United States Geological Survey, and Mr. David Butterfield, Geologist, Vermont Water Resources Department.

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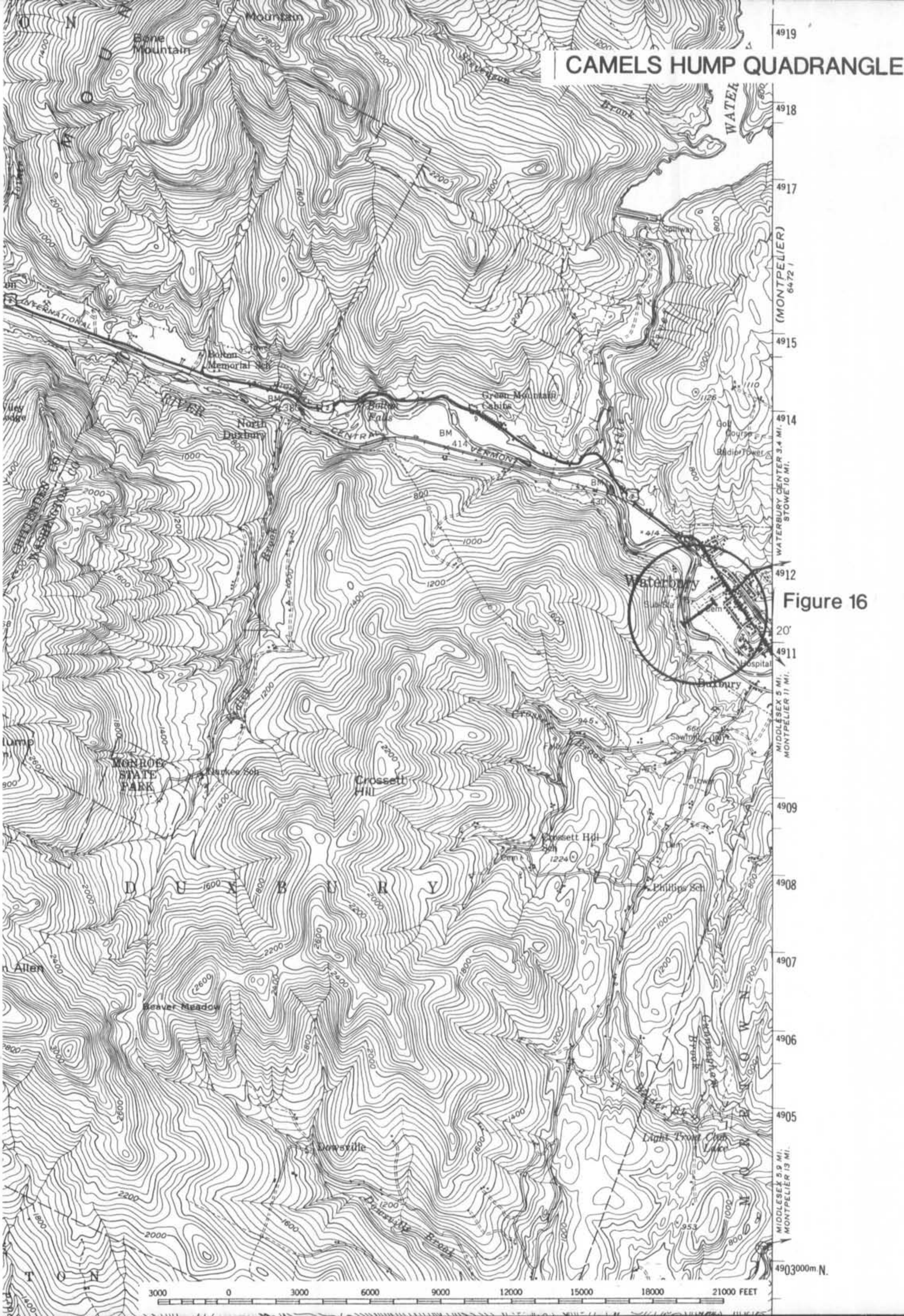
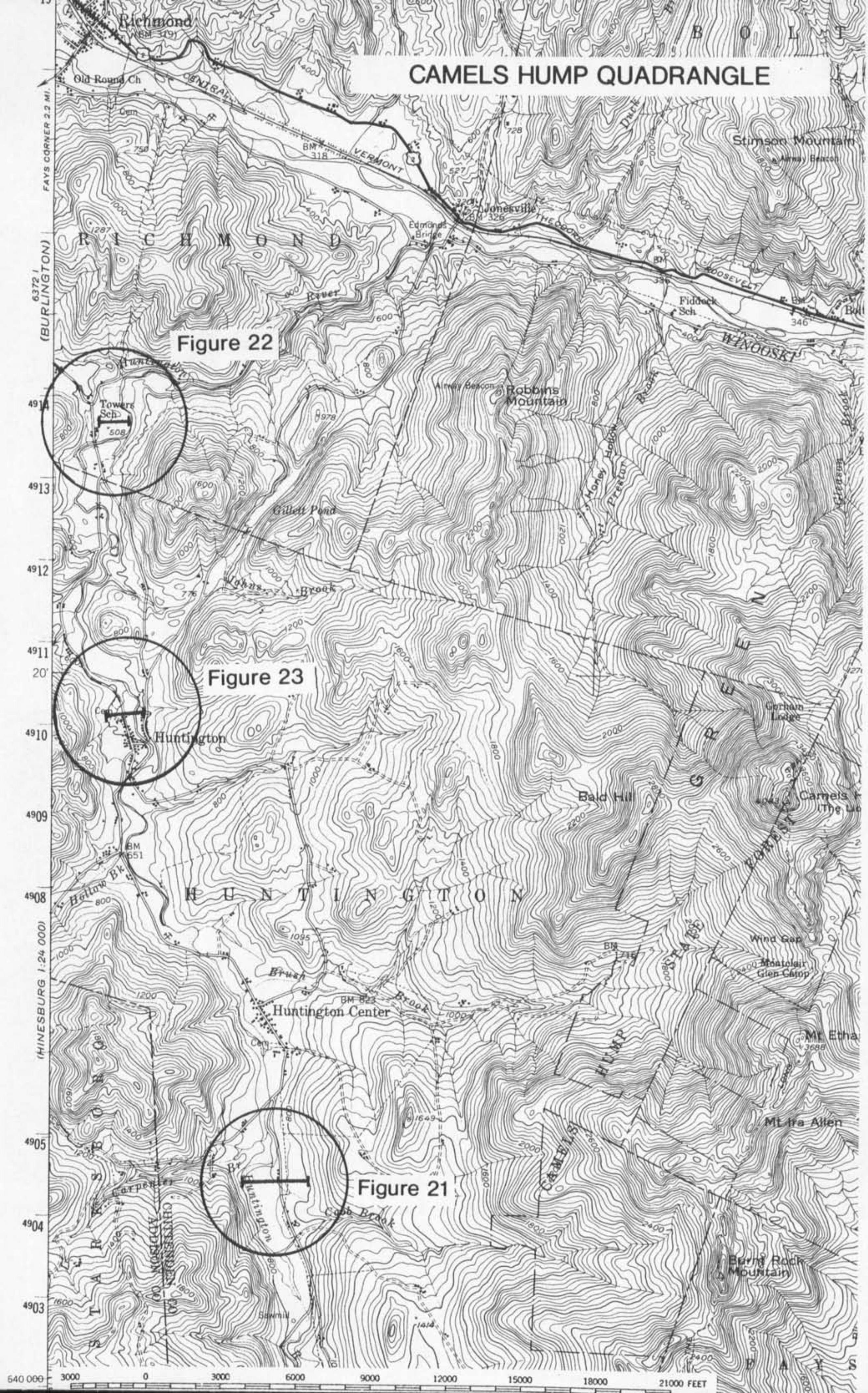
APPENDIX A

MAPS SHOWING FIELD LOCATIONS OF SEISMIC PROFILES

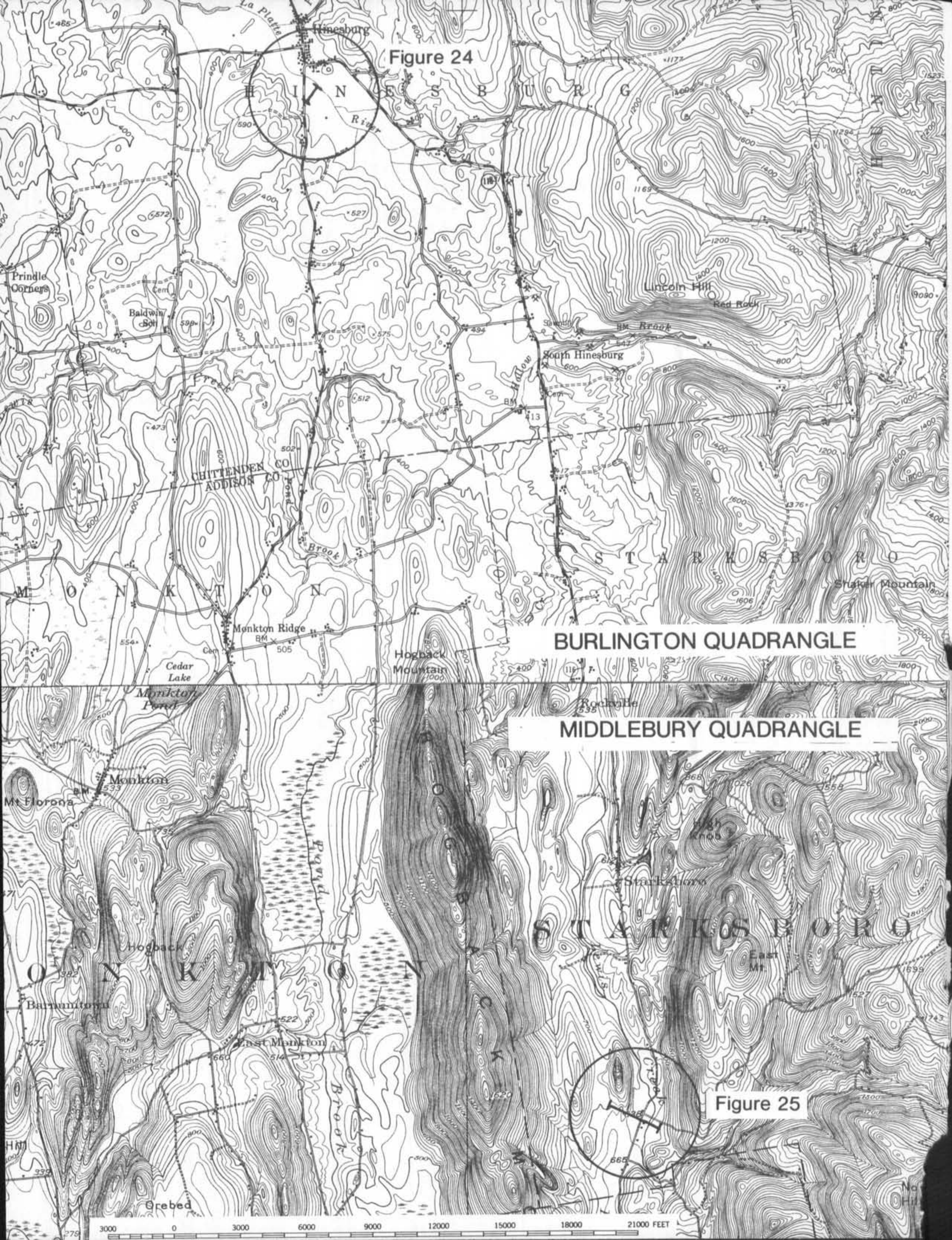

CAMELS HUMP QUADRANGLE
Figure 16
Bone Mountain
Mountain
Bolton Memorial Sch
North Duxbury
Bolton Falls
Green Mountain Cabins
VERMONT CENTRAL
RIVER
Spillway
Golf Course
Radio Tower
Waterbury
Hospital
Duxbury
Crossett Hill
Crossett Hill Sch
Phillips Sch
MONROE STATE PARK
D U X B U R Y
Beaver Meadow
Dowsville
Dowsville Brook
Light Trout Club Lake
(MONTPELIER)
6472 I
WATERBURY CENTER 3.4 MI.
STOWE 10 MI.
MIDDLESEX 5 MI.
MONTPELIER 11 MI.
MIDDLESEX 5.9 MI.
MONTPELIER 13 MI.
4919
4918
4917
4915
4914
4912
4911
4909
4908
4907
4906
4905
4903000m N.
3000 0 3000 6000 9000 12000 15000 18000 21000 FEET


BURLINGTON QUADRANGLE
Figure 18
Figure 17
Essex Junction
ESSEX
Winooski River
North Williston
South Burlington
Burlington Municipal Airport
Kirby Corner
Muddy Brook Sch
Allen Brook
Williston
WILLISTON
Oak Hill Sch
Yantz Hill
Chamberlain Hill
Fays Corner
Richmond
RICHMOND
Brownell Mountain
Shelburne Pond
Lake Iroquois Sch
St George Sch
ST GEORGE
Mount Pritchard
Lake Iroquois
Johnnie Brook
Owls Head
Dow Hill
Rhode Island Corner
Texas Hill
Lower Pond
VERMONT RESEARCH FOREST AGRICULTURAL EXPERIMENT STATION


LINCOLN MOUNTAIN QUADRANGLE
Figure 20
Figure 19
DUXBURY
MORETOWN
Moretown
North Fayston
No 2 School
Huntington Gap
F A Y S T O N
No 3 School
North School
Brook
Camp
No 1 School
Mill
Brook
Waitsfield
Waitsfield Common
East School
Irasville
High Bridge Brook
No 6 School
Dana Hill
Kew Hill
MAD
South School
Scrag Mtn
No 5 School
Folsom Bk
Robinson School
Clay
Brook
Peak
Double Top Mtn
No 7 School
Warren Pinnacle
Bradley Brook
Burnt Mtn
W A R R E N
Sugarloaf Mtn
Warren
East Warren
Warren Road School
Roxbury Gap
South Olive School
Brook
NORTHFIELD



CAMELS HUMP QUADRANGLE
Richmond
Old Round Ch
Jonesville
Edmonds Bridge
RICHMOND
HUNTINGTON
Figure 22
Figure 23
Figure 21
Towers Sch
Huntington
Huntington Center
Gillett Pond
Johns Brook
Robbins Mountain
Stimson Mountain
Fiddock Sch
WINOOSKI
Bald Hill
Gorham Lodge
Camels Hump
Wind Gap
Montclair Glen Camp
Mt Ira Allen
Burnt Rock Mountain
Brush Brook
Cobb Brook
Sawmill
CAMELS HUMP
STATE FOREST
GREEN
(BURLINGTON)
(HINESBURG 1:24 000)
FAYS CORNER 2.2 MI.
4914
4913
4912
4911
4910
4909
4908
4905
4904
4903
640 000
3000 0 3000 6000 9000 12000 15000 18000 21000 FEET



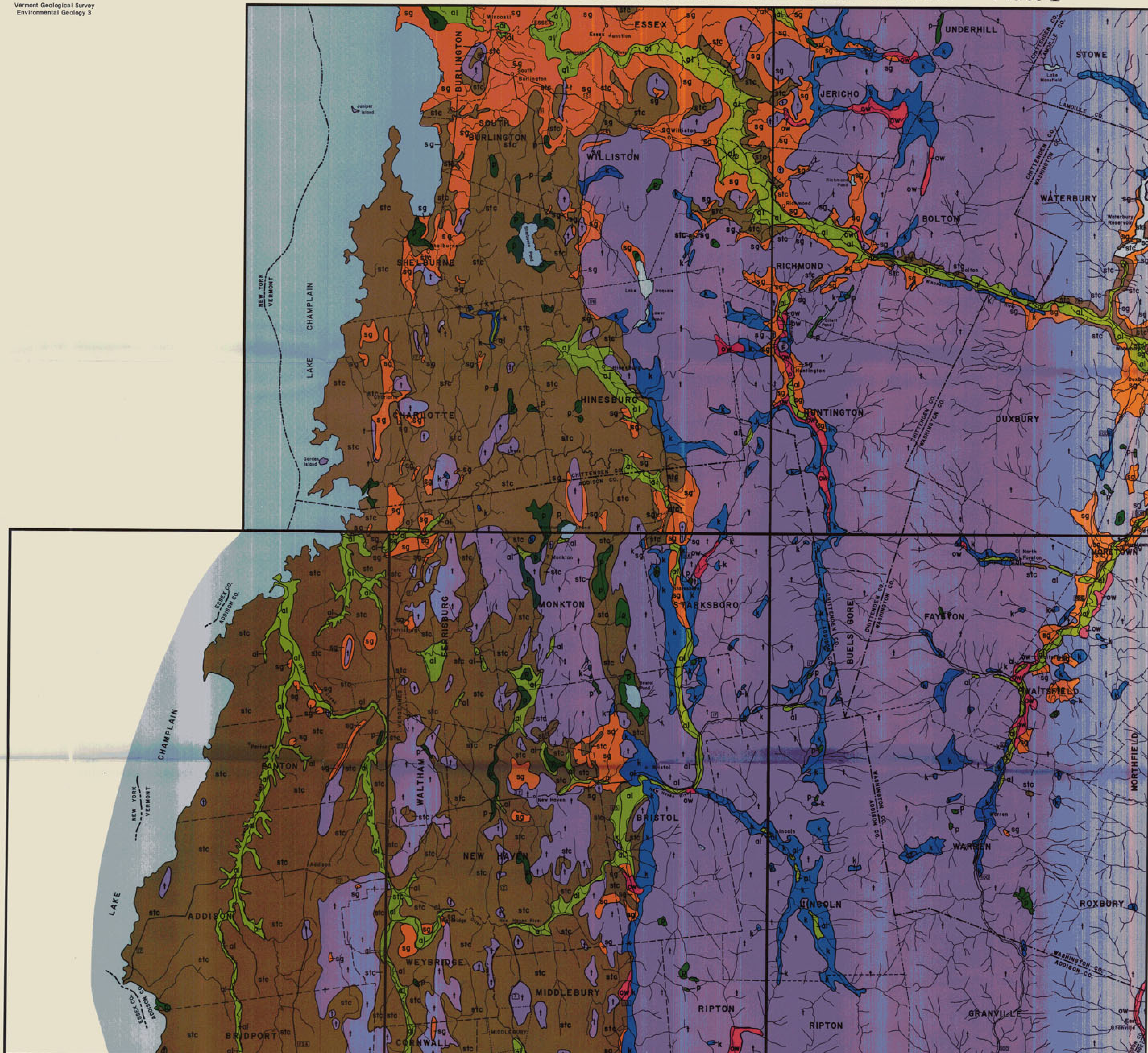
Hinesburg
Figure 24
H I N E S B U R G
La Platte
River
Lincoln Hill
Red Rock
Brook
South Hinesburg
Hollow
Prindle Corners
Baldwin Sch
Creek
CHITTENDEN CO
ADDISON CO
Pond
Brook
S T A R K S B O R O
Shaker Mountain
M O N K T O N
Monkton Ridge
Cedar Lake
BURLINGTON QUADRANGLE
Hogback Mountain
Monkton Pond
Rockville
MIDDLEBURY QUADRANGLE
Monkton
Mt Florona
High Knob
Starksboro
Pond
S T A R K S B O R O
East Mt
Hogback
M O N K T O N
Barnumtown
East Monkton
Brook
Figure 25
Orebed
3000 0 3000 6000 9000 12000 15000 18000 21000 FEET


MIDDLEBURY QUADRANGLE
Figure 26
Figure 27
Figure 28
Bristol
New Haven
New Haven Mills
Bristol Flats
Cedar Swamp
Bald Hill
West Lincoln
South Mountain
North Pond
Gilmore Pond
Cobble
Marble Ledge
Chipman Hill
Middlebury
Ripton
3000 0 3000 6000 9000 12000 15000 18000 21000 FEET

Vermont Geological Survey
Environmental Geology 3

SURFICIAL MATERIAL OF THE BURLINGTON-MIDDLEBURY REGION

Plate I



LEGEND

t — Glacial Till - generally thin over bedrock, much bedrock exposed, unsorted, poorly drained, bouldery surface. Low water potential.

k — Ice Contact Gravel, mostly kame terraces - well sorted, may have a high sand content, well drained above the water table. Good gravel source. High water potential below the water table.

ow — Outwash (valley train) and Fluvial Gravel - in stream valleys, generally well drained above the water table. Fair to good water potential below the water table.

sg — Lacustrine and Marine Sands and Gravels - Marine deposits only along Lake Champlain. Predominantly sand and pbebly sand, well drained above the water table. Good source for sand. Moderate to high water potential below the water table.

stc — Lacustrine and Marine Clays and Silts - Marine sediment only bordering Lake Champlain. Poorly drained. Medium to high plasticity.

p — Peat and Muck - Swampy, poorly drained areas, water table at or near the surface.

al — Recent Stream Aluvium - thin, covering valley floor, poor to moderately well drained, low strength. Poor foundation material.

Scale

1 1/2 0 1 2
miles

true north

Geologic Interpretation by David P. Stewart

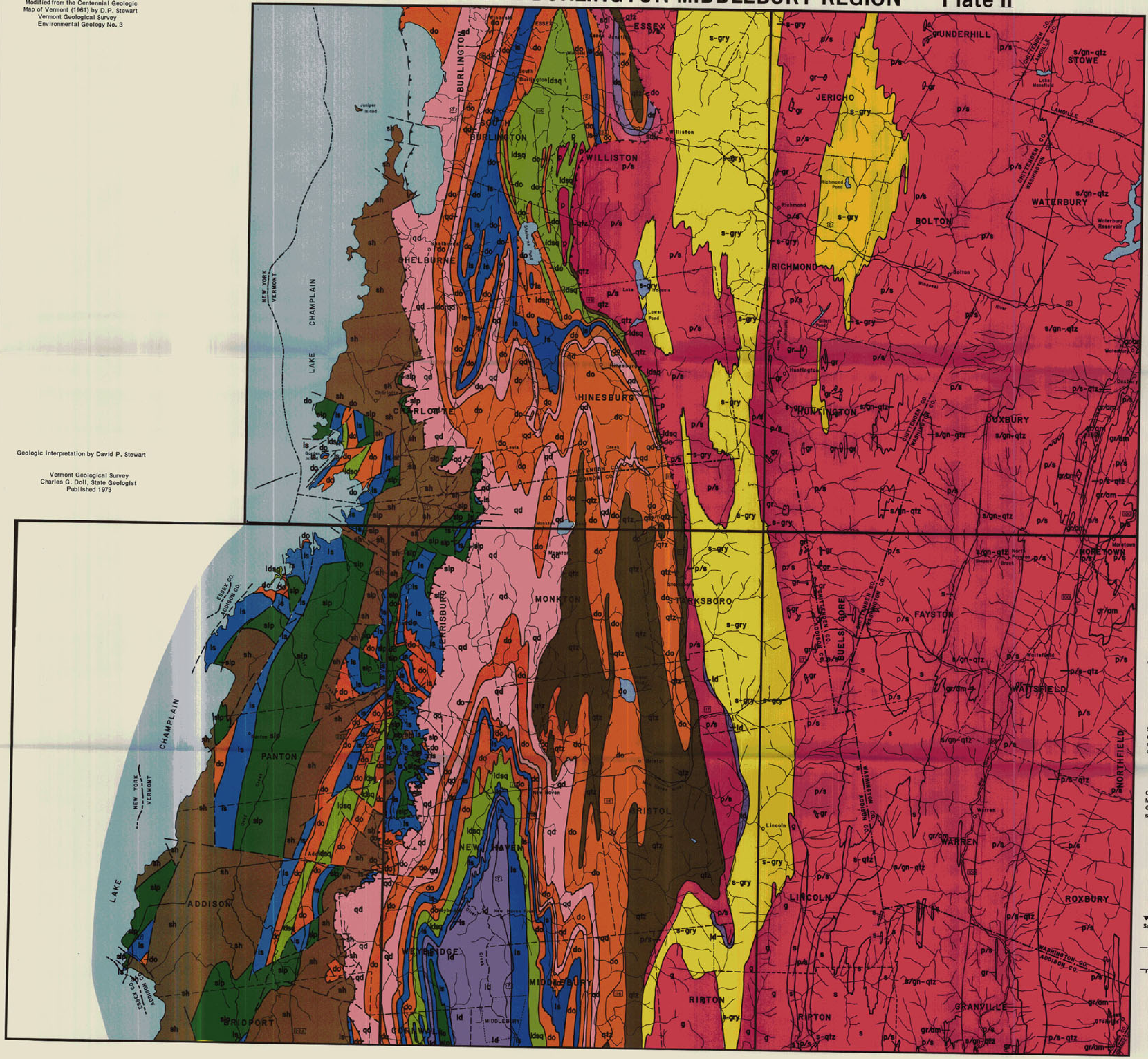
Vermont Geological Survey
Charles G. Doll, State Geologist
Published 1973

BEDROCK OF THE BURLINGTON-MIDDLEBURY REGION Plate II

Modified from the Centennial Geologic
Map of Vermont (1961) by D.P. Stewart
Vermont Geological Survey
Environmental Geology No. 3

Geologic interpretation by David P. Stewart

Vermont Geological Survey
Charles G. Doll, State Geologist
Published 1973



LEGEND

CHAMPLAIN LOWLAND

qtz

Quartzite. Very resistant to both physical and chemical weathering and erosion. Forms most of the high relief on the Champlain Lowland. Medium to fine texture, massive, usually fractured.

ls

Limestone (Marble). Medium coarse grained in the southern portion, fine grained in the north. Quite susceptible to chemical weathering and erosion. Fractures generally enlarged by solution weathering. Moderately resistant to physical weathering.

do

Dolomite (Marble). Less susceptible to chemical weathering than limestone, but solution weathering active along fractures. More resistant to physical weathering and erosion than limestone.

sh

Shale (Slate). Resistant to chemical weathering. Susceptible to physical weathering and erosion. Generally highly fractured.

ds

Dolomite and Sandstone. Sandy dolomite and dolomite conglomerate with interbeds of sandstone. Sand content increases resistance to erosion.

ld

Limestone and Dolomite. Occasional interbedded shale. Solution weathering along fractures.

qd

Quartzite and Dolomite. Quartzite with occasional relatively thick dolomite layers or alternating layers of quartzite and dolomite of about equal thickness. Includes some massive quartzite in southwest corner of map. Generally resistant to both physical and chemical weathering and erosion.

sdl

Interbedded Slate, Dolomite, Sandstone, Limestone, and Shale. Resistance to weathering varies with content of sandstone and slate.

slp

Undifferentiated Slate, Limestone, and Phyllite. Usually fractured, moderately resistant to erosion.

ldsq

Interbedded Limestone, Dolomite, Sandstone, and Quartzite. Generally resistant to erosion.

GREEN MOUNTAINS

s-gry

Schistose Greywacke. Complex, light to dark grey color, highly metamorphosed, sandy. Generally resistant to erosion, but dark minerals susceptible to chemical weathering.

Complex, highly metamorphosed rocks of the Green Mountains consisting primarily of Phyllites, Gneisses, Schists with varying amounts of Greenstones and Amphibolites. Highly fractured.

- g - gneiss
- s - schist
- p - phyllite
- gr - greenstone
- p/s - undifferentiated phyllites and schists
- s-qtz - schists with interbedded quartzite
- gr/am - undifferentiated greenstones and amphibolites
- s/gn-qtz - undifferentiated schists and gneisses with interbedded quartzite
- p/s-qtz - undifferentiated phyllites and schists with interbedded quartzite

Thrust fault. Dashed when inferred. Sawteeth on upper plate.

Normal fault. Dashed when inferred.

Reverse fault. Dashed when inferred.

Scale

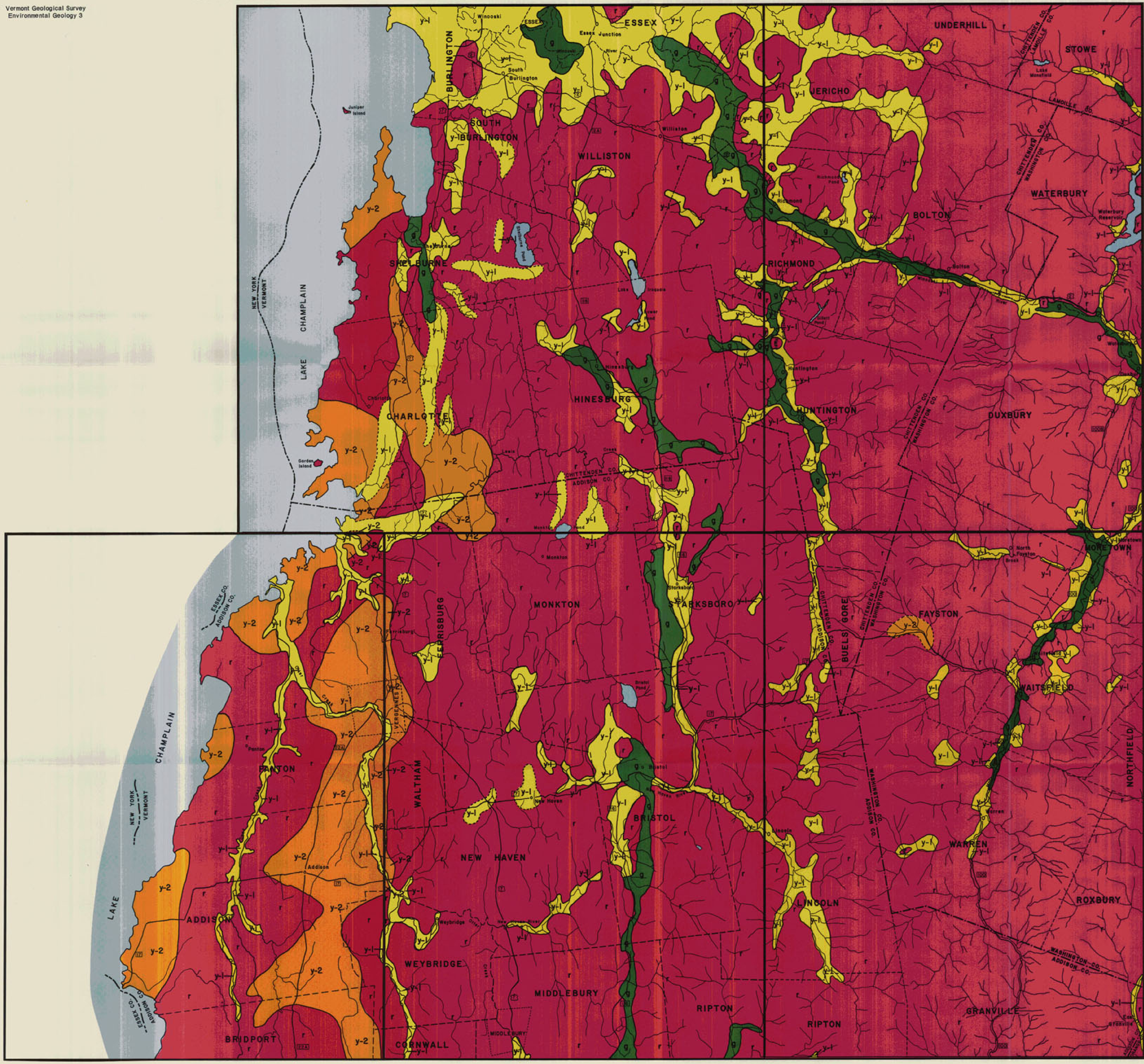
1 1/2 0 1 2

miles

true north

GROUND WATER POTENTIAL MAP OF THE BURLINGTON-MIDDLEBURY REGION Plate III

Vermont Geological Survey
Environmental Geology 3



LEGEND

g

Areas of good ground water potential. Water available in sand and gravel deposits in stream valleys or buried valleys. Water yield medium to high from the unconsolidated sediments.

y-l

Areas of moderate ground water potential. Water available from sand and gravel in stream valleys or from bedrock below the valley fill. Water yield low to medium at depths to 300 feet.

y-2

Areas of low to moderate ground water potential. Water available from fractures in the rock in zones of complex faulting. No statistical data available in these areas to give estimates of the potential water yield.

r

Areas of very low ground water potential. Water available in these areas from low yield, bedrock sources to depths of 300 feet.

Buried Valley with Inferred Boundary.

Scale

1 1/2 0 1 2

miles

true north

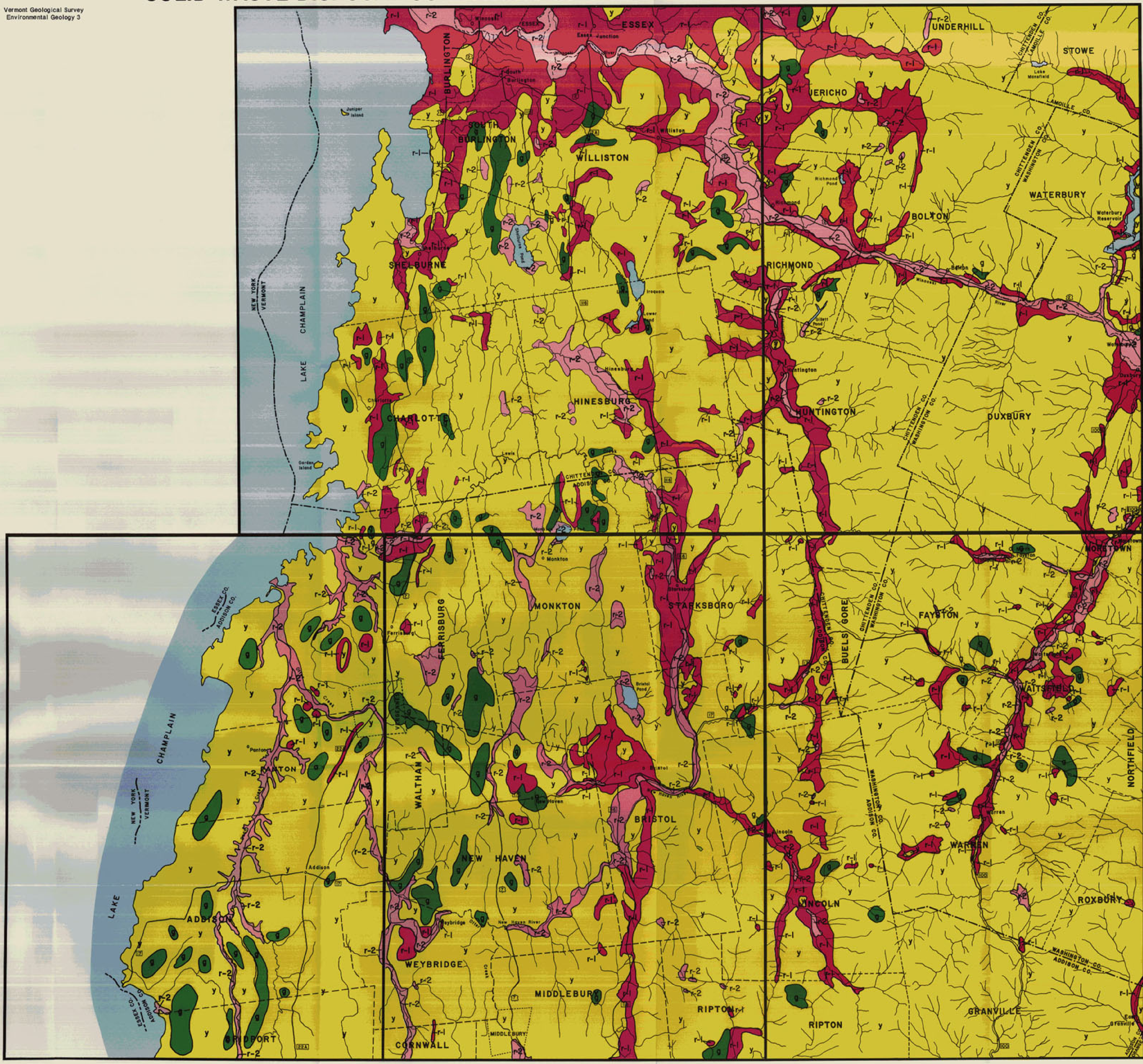
Geologic interpretation by David P. Stewart

Vermont Geological Survey
Charles G. Doll, State Geologist
Published 1973

Vermont Geological Survey
Environmental Geology 3

SOLID WASTE DISPOSAL CONDITIONS OF THE BURLINGTON-MIDDLEBURY REGION

Plate IV



LEGEND

g — Areas of impermeable tills, silts and clays generally over 25 feet thick. Suitable for solid waste sanitary landfill with proper surface drainage precautions.

y — Areas of till over bedrock. Till cover usually thin with areas of bedrock exposed at the surface. Solid waste sanitary landfill only where till is over 30 feet thick and with proper surface drainage precautions. Contamination of ground water probable from barns, domestic sewage systems, landfills, etc., in areas of exposed bedrock or a till cover of less than 15 feet.

r-1 — Areas of sand and gravel with medium to high permeability and medium to high water potential. Unsuitable for solid waste sanitary landfill.

r-2 — Poorly drained, swampy areas. Mostly stream valley floodplains with low relief and periodic flooding. Unsuitable for solid waste sanitary landfill.

Scale

1 1/2 0 1 2
miles

true north

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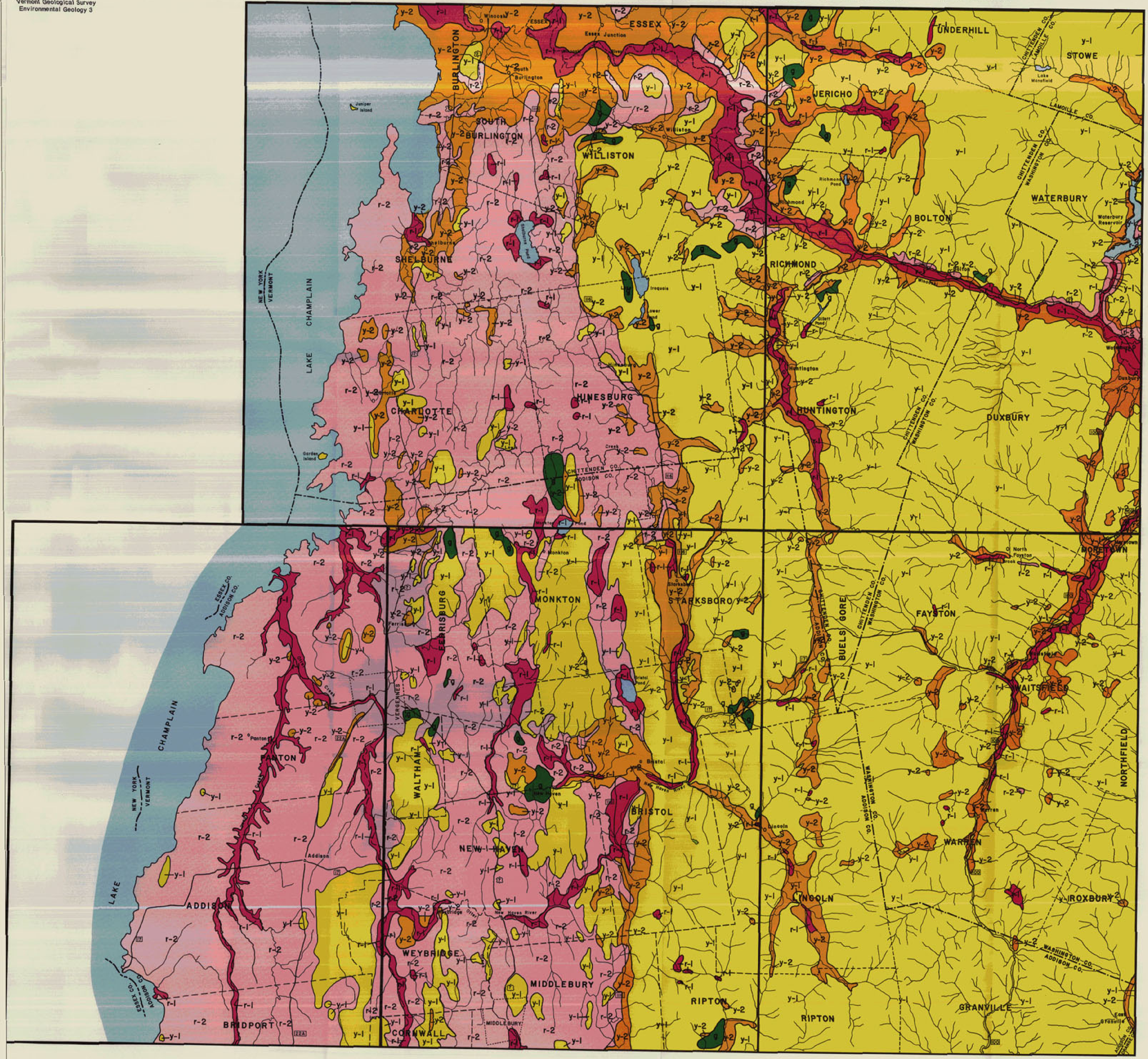
SEPTIC TANK CONDITIONS OF THE BURLINGTON-MIDDLEBURY REGION Plate V



LEGEND

g — Areas of till over 25 feet thick. Low to medium permeability. Suitable for septic tanks with leaching fields at least 200 feet long.

y-l — Areas of thin till over bedrock. Bedrock commonly exposed at the surface. Septic tanks with at least a 200-foot leaching field only in areas where till is over 10 feet in thickness.

y-2 — Areas of permeable sands and gravels. Suitable for septic tank use if deposit is over 15 feet thick and water table is over 25 feet below ground surface. Silt, clay or till below at least 6 feet of sand or gravel is desirable to prevent downward movement of affluent.

r-1 — Low, poorly drained, frequently flooded stream floodplains covered with alluvium and/or swamps. Unsuitable for septic tanks.

r-2 — Areas of silts and clays with very low permeability. Septic tanks will not function properly in these areas.

Scale

1 1/2 0 1 2
miles

true north

Geologic interpretation by David P. Stewart

Vermont Geological Survey
Charles G. Doll, State Geologist
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GENERAL CONSTRUCTION CONDITIONS OF THE BURLINGTON-MIDDLEBURY REGION Plate VI

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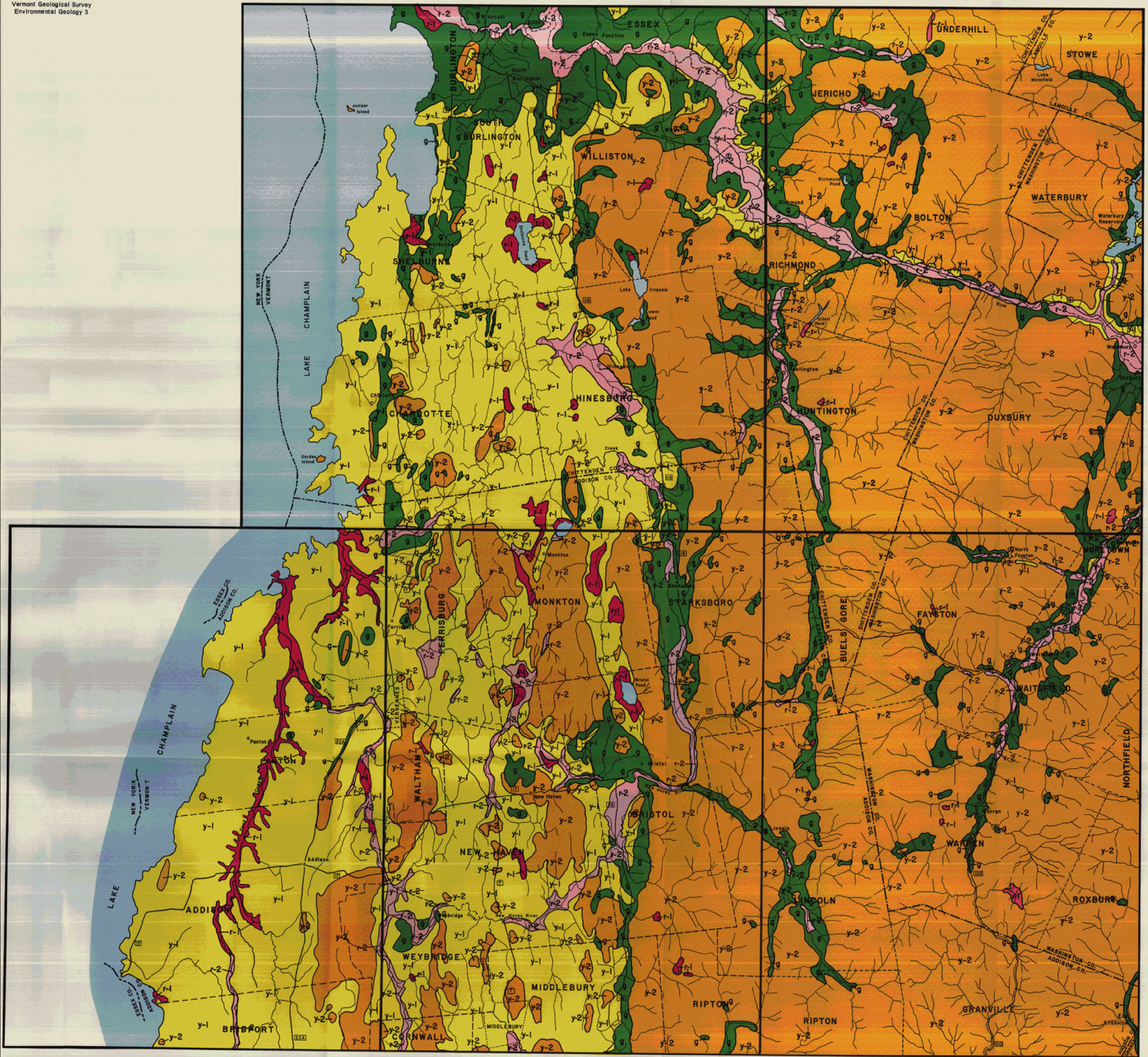

LEGEND

g

Areas of thick, well drained sand and gravel deposits with adequate bearing strength.

y-1

Areas of lake sediment composed predominantly of silt and clay. May or may not be capped with sand and/or gravel. Steep slopes common on the outer margins of terraces.

y-2

Areas of till and bedbock. Till cover generally less than 20 feet. Permeability of till very low. Wide areas have bedrock exposed at the surface or bedrock with less than 5 feet of till.

r-1

Areas of poor drainage and swampy conditions. Ground water level near or at the surface. Contains wet, compressible sediment.

r-2

Areas of stream bottom-land covered with 10 to 25 feet of alluvium. Subject of frequent flooding. Alluvium unsuitable for foundations of heavy structures.

Scale

1 1/2 0 1 2
miles

true north

Geologic interpretation by David P. Stewart

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SAND AND GRAVEL RESERVES OF THE BURLINGTON-MIDDLEBURY REGION Plate VII

Vermont Geological Survey
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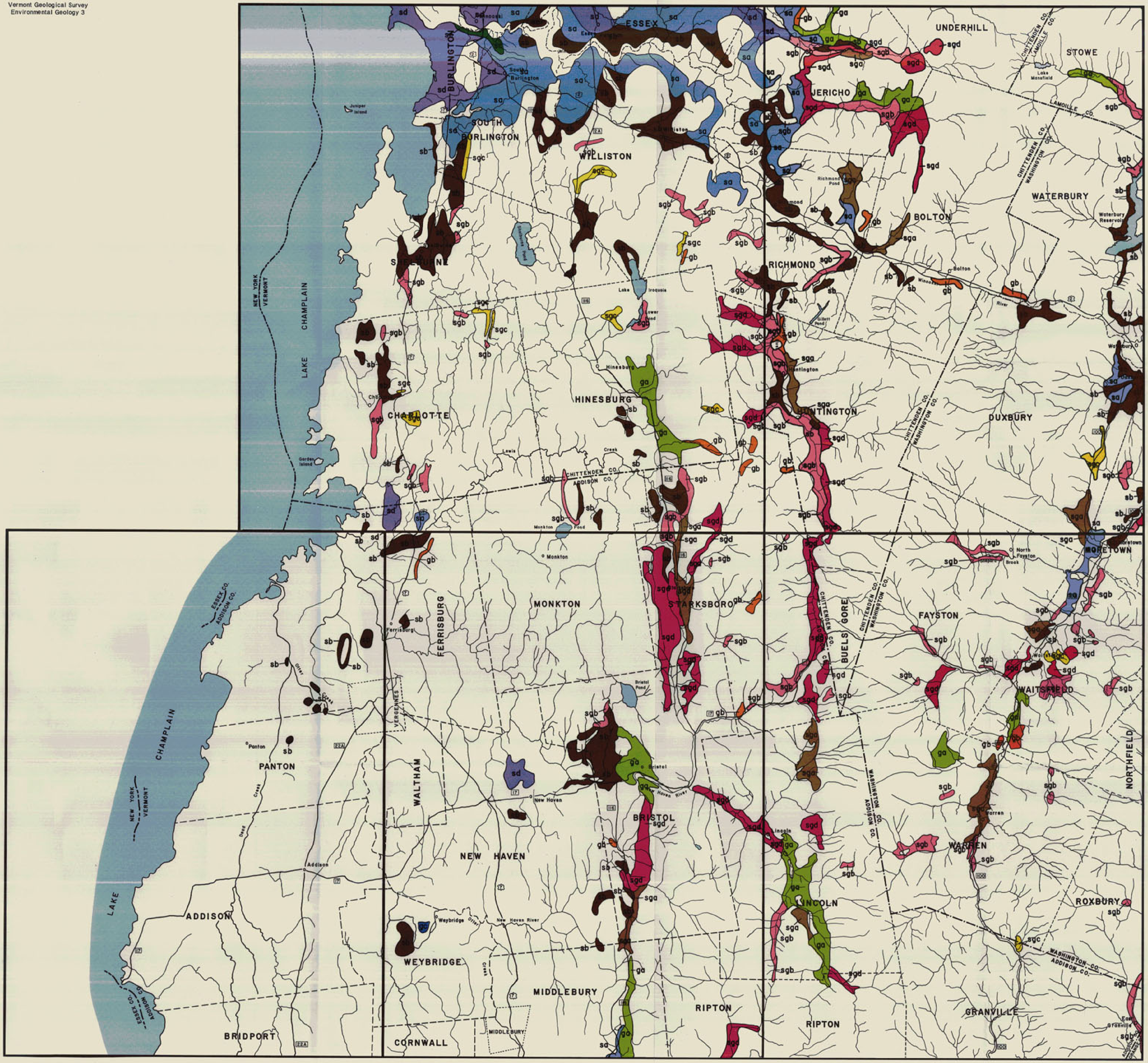

LEGEND

ga — Gravel deposits containing less than 25% sand. Medium to good quality. Large reserve. Less than one-half the original reserve depleted.

gb — Gravel deposits containing less than 25% sand. Low to medium quality. Low to medium reserve. Less than one-half original reserve depleted.

gc — Gravel deposits. Medium to good quality. Low to medium reserve. Over one-half of the original reserve depleted.

sga — Sand and gravel deposits of medium to good quality and large reserve. Less than one-half original reserve depleted.

sgb — Sand and gravel deposits of low to medium quality and low to medium reserve. Less than one-half of the original reserve depleted.

sgc — Sand and gravel deposits. Medium to good quality. Over half of the original reserve depleted.

sgd — Sand and gravel deposits of unknown quality and reserve.

sa — Sand deposits containing less than 25% gravel. Medium to good quality. Large reserve. Less than one-half of the original reserve depleted.

sb — Sand deposits containing less than 25% gravel. Low to medium quality. Low to moderate reserve. Less than one-half of original reserve depleted.

sc — Sand deposits. Medium to high quality. Over one-half of original reserve depleted.

sd — Sand deposits of unknown quality and reserve.

Scale

1 1/2 0 1 2
miles

true north

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