GEOMORPHOLOGY, PALEOCLIMATOLOGY AND LAND USE CONSIDERATIONS OF A GLACIATED KARST TERRAIN; ALBANY COUNTY, NEW YORK

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ABSTRACT

Karstified terrains in Albany County, New York provide evidence of paleoclimatic conditions during Pleistocene glaciation. Caves and the areas surrounding them preserve important clues that can be interpreted to reconstruct portions of the geomorphic and paleoclimatic history of a region. Knowledge gained from these investigations is of increasing importance as development pressures extend into these forested, agricultural and rural areas. This paper focuses on the geology, karst hydrology, and glacial features of two areas not previously described. As a result of karst processes and anthropogenic diversion of the headwaters of the Onesquethaw Creek, the Hollyhock carbonate aquifer and its receiving stream (i.e., Onesquethaw Creek) are extremely sensitive to contaminant inputs. Thus, we have incorporated a section specific to land use considerations and concerns. This ongoing work is an extension of previous work addressing the interaction between karst and glaciation (Rubin, 1991b; Palmer et al., 1991a, 1991b).

Two karst areas will be visited on this field trip. The first stop, at the Hollyhock Hollow Sanctuary, will feature a cave system that 1) developed prior to the advance of the late Wisconsinan (Woodfordian) Laurentide ice sheet; 2) was enlarged by meltwater invasion; and 3) remains active today. The second stop will be at Joralemon Park, where active and relict caves are used to interpret the interaction between caves and glacial processes. Solutionally enlarged fractures and relict caves and swallow holes in the groundwater basin are integral, functioning components of the epikarst, funnelling runoff and infiltrating meteoric waters to deeper conduit flow routes.

INTRODUCTION: HOLLYHOCK HOLLOW SANCTUARY

The Hollyhock Hollow Sanctuary and surrounding area represent a unique geologic and hydrologic setting. The Hollyhock carbonate aquifer supports no surface drainage today, except for the Onesquethaw Creek which is seasonally pirated underground for ≈ 1 km (0.7 mi). All drainage is subsurface in limestone bedding planes, joints, faults and conduits, largely within the Manlius and Coeymans Limestones. Structural deformation here within the Hudson Valley Fold Thrust belt has folded and faulted these limestone units. This deformation is locally responsible for orienting subsurface flow paths

In Garver, J.I., and Smith, J.A. (editors). Field Trips for the 67th annual meeting of the New York State Geological Association, Union College, Schenectady NY, 1995, p. 81-107.

and was in place prior to Wisconsinan glaciations. During glaciation, subglacial meltwater carved shallow bedrock channels in the Coeymans Limestone. Several relict caves and perhaps the only known meltwater-carved limestone pedestals in such a setting attest to the unique geology of this karst basin. Scallops (solutional pockmarks in cave walls) in swallow holes document former rapid surface and groundwater flow here. Some of this meltwater was pirated into now relict swallow holes over many thousands of years. This same flow created or enlarged limestone cave conduits which today still drain the carbonate groundwater basin that extends to the north and northwest. These enlarged joints and conduits provide a route for possible rapid transport of contaminants.

Location stops for this field trip are organized sequentially for walking tours.

HOLLYHOCK HOLLOW STUDY AREA BOUNDARIES

The Hollyhock Hollow study area is located in Albany County, New York along the Onesquethaw Creek, a tributary to the Hudson River. The larger study area is bounded by the Onesquethaw Creek to the southwest, the Manlius/Coeymans escarpment to the north and northeast, extends a short distance east of Route 102, and may extend beyond Rowe Road to the west. A smaller area within this broad area, extending outward from the Hollyhock Hollow Sanctuary property, is the focus of the field trip stop. The study area is located in the Towns of New Scotland and Bethlehem.

GEOLOGY

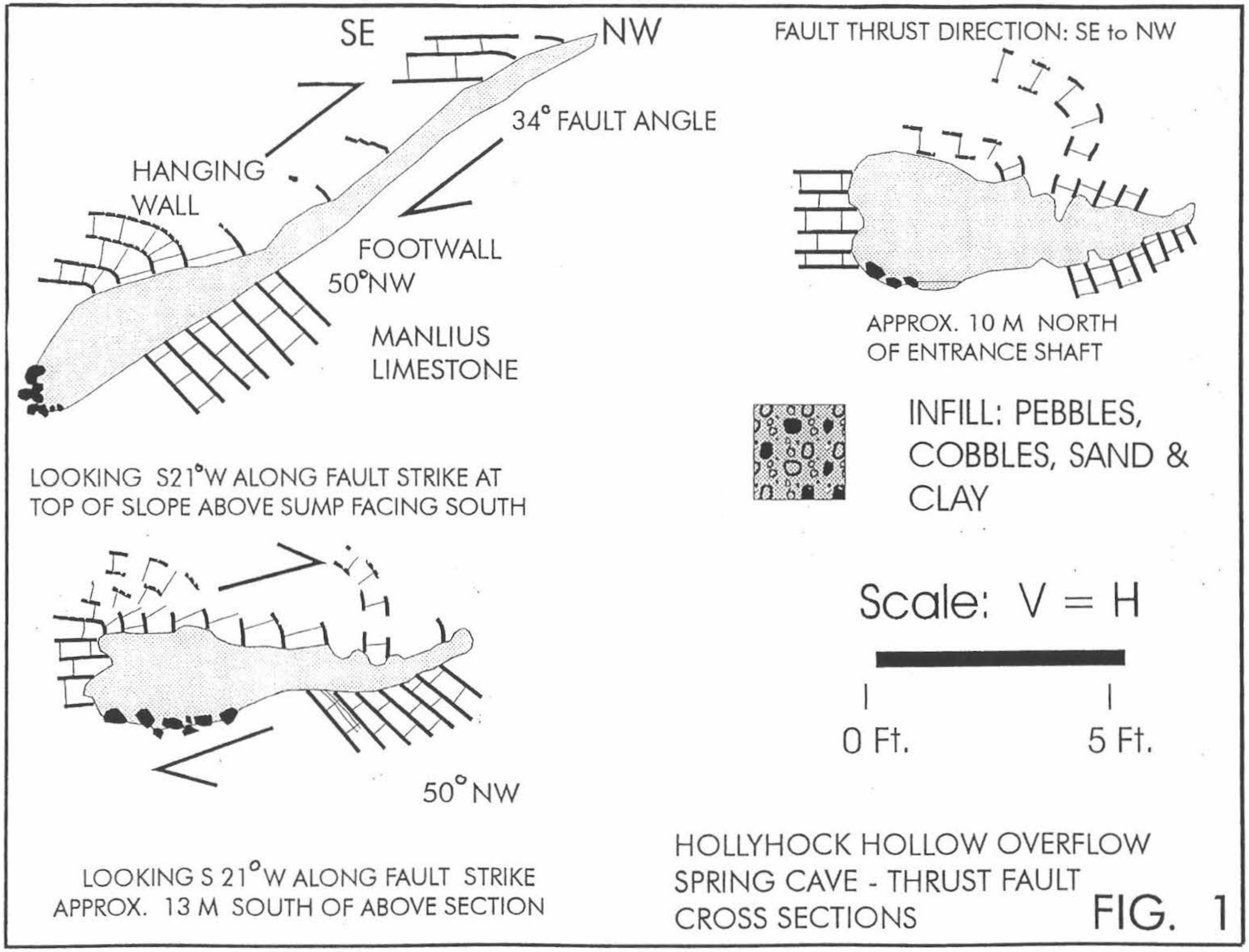
The Hollyhock carbonate aquifer is developed predominantly in the Lower Devonian Manlius and Coeymans limestones, with small outcrop areas of the Kalkberg and New Scotland formations. The massive and blue-gray, thick-bedded Coeymans Formation is the uppermost bedrock unit exposed throughout most of the drainage basin. Infiltration of meteoric water through vertical fractures recharges the underlying carbonate aquifer. These fractures, and those extending into the underlying Manlius Limestone, comprise the epikarst - the unsaturated upper part of the percolation zone. Locally, within the Hollyhock Hollow Sanctuary, these fractures have historically been exploited for dimension stone. Thin "millimeter" beds are characteristic of the Manlius Limestone.

The Hollyhock Hollow Nature Sanctuary, Joralemon Park and surrounding areas are situated within the Hudson Valley Fold-Thrust Belt (HVB) and exhibit faulting characteristic of this belt. Marshak (1986, 1990), Marshak and Engelder (1987), and Cassie (1990) discuss structural deformation within parts of the HVB. Marshak (1990) addresses the spectacular cross section of a detachment fault, a duplex, and a ramp anticline in the Feura Bush Quarry situated north and probably within the Hollyhock groundwater basin.

While evidence of faulting is present in the area and does locally disrupt the regional bedrock dip, it is hypothesized that the overriding control on groundwater flow in most of the Hollyhock carbonate aquifer is the local dip. Preliminary geologic mapping in the vicinity of Hollyhock Hollow reveals bedrock strikes and dips ranging between N2°E and N34°E, and 4°SE and 14°SE, respectively.

HOLLYHOCK HOLLOW OVERFLOW SPRING CAVE

A large groundwater basin is tributary to the Hollyhock Hollow Overflow Spring. The overflow spring flows only during periods of heavy snowmelt or storm water infiltration. The gated entrance shaft ($\approx$ 9 m; 30 ft) is developed along a vertical joint that was filled with boulders and rubble sometime in the last 250 years, then partially capped with concrete. It was opened in 1994 by cavers in cooperation



LOOKING S21°W ALONG FAULT STRIKE AT TOP OF SLOPE ABOVE SUMP FACING SOUTH

APPROX. 10 M NORTH OF ENTRANCE SHAFT

LOOKING S 21°W ALONG FAULT STRIKE APPROX. 13 M SOUTH OF ABOVE SECTION

HOLLYHOCK HOLLOW OVERFLOW SPRING CAVE - THRUST FAULT CROSS SECTIONS

FIG. 1

with New York Audubon. At the base of the entrance shaft, a low, wet, and muddy cave may be followed for approximately 38 m (125 ft) to a sump. The presence of a rounded 36 cm (14 in) diameter quartzite boulder near the farthest point of penetration in this overflow cave indicates high discharges and velocities through large conduits. The nearest likely source of this boulder is from the Rienow Swallow Hole (see below), some 600 m (2,000 ft) to the north.

The Hollyhock Hollow Overflow Spring Cave has developed along a thrust fault and related fractures in the Manlius Limestone (Fig. 1), striking north-northeast and upthrown to the northwest, indicating the possible importance of faulting and fault-related fractures for cave development and groundwater flow in the HVB. Conduit enlargement preferentially occurred along a structurally weakened zone of increased permeability. In order to assess the importance of the structural geology on groundwater flow, excavation efforts are underway in an effort to gain entry into upgradient conduit portions of the carbonate aquifer.

Based on observations made by New York Audubon staff, Rubin (1994a) calculated an estimate of groundwater discharge from this overflow spring. While further hydrologic work is required to refine the discharge estimate, some 1.3 m^3/s (47 cfs; 21,000 gpm) flowed during a 2-day storm event (calculated using the Hazen-Williams equation for turbulent pipe-full flow conditions), indicating a groundwater basin contributing flow from at least 9 km^2 (3.5 mi^2). Tracer tests are required to define the extent of the groundwater basin.

The formation of this floodwater overflow spring could have resulted from one or more of the following factors: 1) the relative inefficiency of the occluded base flow springs situated south of this overflow spring (see Spring Zone section); 2) the increased discharge from a thin soil-mantled and well-karstified carbonate unit; or 3) the invasion of large quantities of glacial meltwater through swallow holes and fractures.

Scallops (solutional pockmarks) on the walls of Wiltsie's Cave and the Rienow Swallow Hole (see Rienow Swallow Hole and Wiltsie's Cave sections) document even larger supercritical turbulent paleoflows (to 55 cfs) into this groundwater basin (Rubin, 1994b) that, when considered with other inputs from throughout the broad watershed, attest to the maturity and drainage efficiency of the basin. Thus, groundwater from a large drainage area flows into the Hollyhock Hollow Sanctuary. Land uses far beyond the Hollyhock Hollow property boundaries have the potential to degrade groundwater and surface water quality at and downgradient of the sanctuary.

Geomorphic And Karst Considerations

How long has the Hollyhock Hollow Overflow Spring Cave operated as a floodwater overflow route? Dineen (1987) and Isachsen et al. (1991) document that this area has been modified by stream incision and physical weathering during the Cenozoic era (last 65 my). Dineen (1987) determined that present-day drainage trends in the Hudson Valley were established before Wisconsinan glaciations, sometime prior to 70,000 years ago. Evidence that today's drainage was in place prior to inundation by Woodfordian ice includes 1) glacial striations near Clarksville cut across the channel of the Onesquethaw Creek, and 2) insufficient time for denudation and erosion rates to incise the channel to the striated level during post-Woodfordian time. Wisconsinan drainage along Onesquethaw Creek was probably little different from what it is today. Thus, the physical setting was in place for the piracy of meteoric water into limestone fractures and subsequent flow to the base level Onesquethaw Creek.

$^{230}Th/^{234}U$ dating of speleothems from Schoharie County caves provides evidence of initial cave development in the region prior to 350 Ka, the limit of this dating method. Based on evidence of well-adjusted drainage patterns in the Cenozoic era, it is possible that cave development has been ongoing over the last several million years. ^{230}Th/^{234}U disequilibrium series dating of speleothems from Schoharie County caves reveals dates between 277 Ka and 165 Ka, and greater than 350 Ka (Dumont, 1995 and Stein-Erik Lauritzen [cited in Palmer et al., 1991a]) indicating active karstification throughout the region for hundreds of thousands of years. Rubin (1991b) provides additional evidence that preglacial caves were modified and enlarged by the invasion of glacial meltwaters. Thus, the physical setting for development of the floodwater overflow route was probably in place prior to the last glaciation. The presence of boulders and large cobbles in the overflow route, in the absence of a likely surficial input location under present day climatic conditions, suggests that enlargement of this route occurred either during Wisconsinan glaciations or before, when even greater flows occurred through the cave system.

RIENOW LEGACY

The karst hydrology (e.g., karren, caves and lack of surface drainage) clearly documents that a well-developed carbonate aquifer and related cave system underlies a many square kilometer area. To date, only small caves have been entered at various points throughout the basin. For the flashy high-discharge Hollyhock Hollow Overflow Spring to function, an extensive and well-integrated cave system must be present. Entry into the system (assuming much of it is physically traversable) will permit additional aquifer characterization; geomorphic, structural, and hydrologic assessment; and water quality evaluation within some of the groundwater basin. At this time, digging efforts are focused on the Rienow Swallow Hole.

Geologists and cavers attempting to gain access to the Hollyhock carbonate aquifer may not be the first. A detailed and tantalizing two-page New York State Historic Trust form, filled out by Professor Robert Rienow (deceased former owner of the property) in 1973, has one sentence describing "caves" on the 56 hectare (138 acre) Hollyhock Hollow Farm. Specifically,

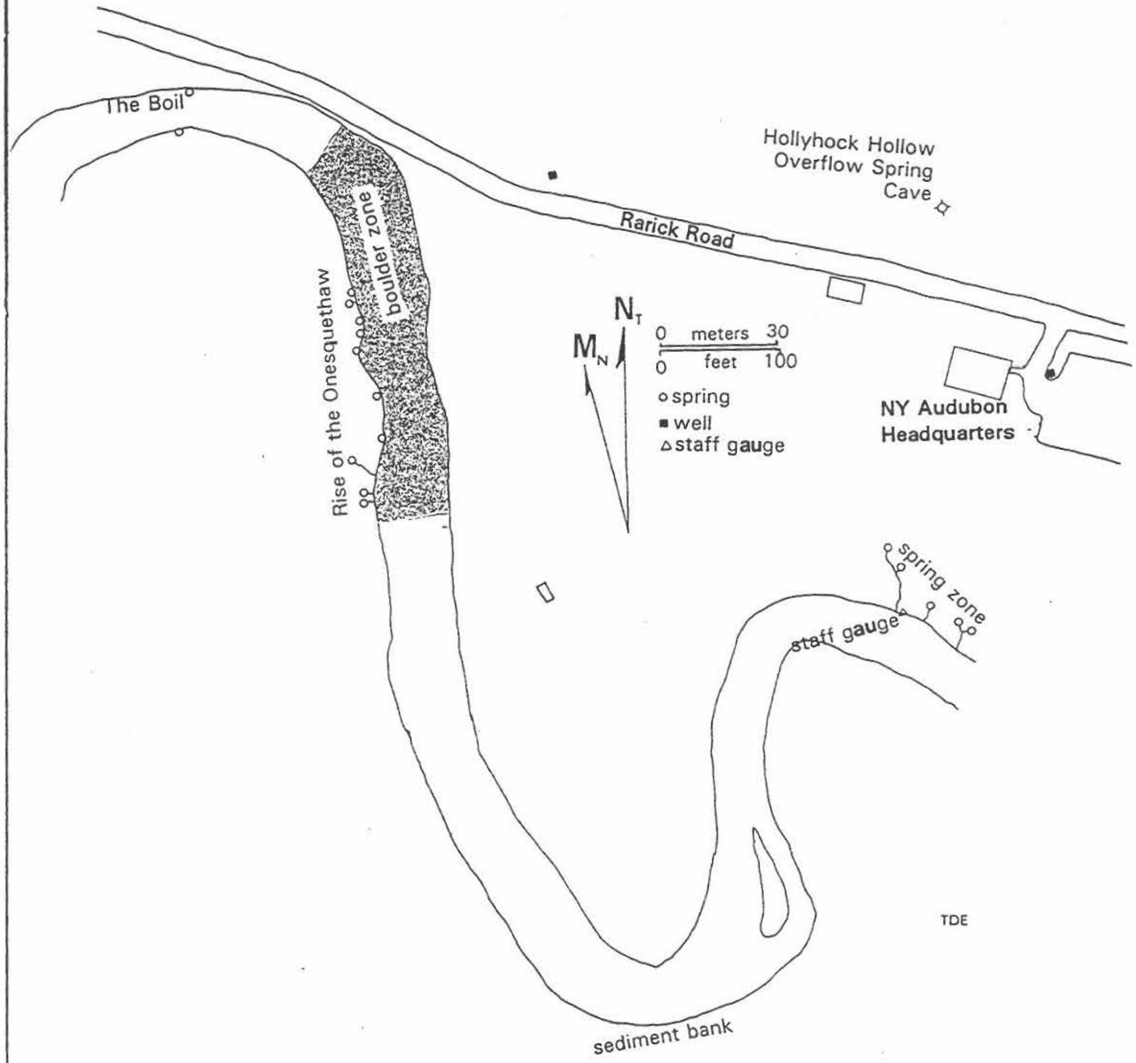
> *"Of historic interest, as well as geologic, the entire farm is honeycombed with caves which as late as 1940 still had rope ladders for access 50 feet down (now closed)."*

This reference, especially when taken in conjunction with other factual references provided on the form, strongly points to the presence of a large, formerly enterable, cave on the property. While Professor Rienow did not describe the location of the access point, we know that it could not have been Wiltsie's Cave since access did not require rope ladders, it was not on his property, and it was not closed. Furthermore, the Hollyhock Hollow Overflow Spring Cave near Rarick Road does not fit the description, would not be considered accessible by most and does not suggest the term honeycombed. Other access options include assorted boulder piles (possibly covering a shaft entrance) and a second sinkhole (with a small cave) east of the Rienow Swallow Hole.

SPRING ZONE: RESURGENCE POINT FOR THE HOLLYHOCK CARBONATE AQUIFER

During periods of low and moderate flow, the Hollyhock carbonate aquifer and integrated cave system resurge or drain through five alluviated springs, the number depending on the amount of water incident to the cave system and the elevation of backflooding behind the occluded bedrock outlet (Fig. 2). While these springs still flow during periods of high flow, their efficiency is exceeded, causing water to backflood within the cave system, and sometimes discharge out the overflow spring. The springs are situated downhill and south of the headquarters building and to the east and west of the staff gauge. The five low and moderate flow springs probably issue from a single bedrock outlet now occluded by a combination of till, deltaic, and perhaps lacustrine deposits. These springs are distinct from springs on the creek's western side that form The Rise of the Onesquethaw (see section below).

Figure 2 - Springs along the Onesquethaw



STAFF GAUGE AND RATING CURVE DEVELOPMENT (WATER QUANTITY)

The importance of baseline Onesquethaw Creek water quantity and quality data may one day be critical, should surface water withdrawals or impoundments or waste-water/leach field (surface and subsurface) additions be proposed along the Onesquethaw Creek Corridor. As developmental pressures build in this area and along the Onesquethaw Creek Corridor, it is becoming increasingly important to understand the flow dynamics of the Onesquethaw and its tributary aquifers and their assimilative capacity for contaminants. While a detailed, but short-term (15^+ month), record of streamflow was kept farther upstream in Clarksville in the mid-1980s (Rubin, 1991a; 1992), installation of the Hollyhock Hollow staff gauge represents the first effort to maintain long-term discharge records along the Onesquethaw Creek.

This gauging station is in a critical location since the Onesquethaw Creek is a losing stream upstream of The Boil (see below), with flow occurring in solutional conduits during much of the year. The staff gauge was installed in November 1994 in cooperation with New York Audubon, which records stream stage daily. A rating curve is being developed. Continuous recording of stage height, coupled with hydrologic data from the cave system, should permit detailed analysis of the relationship between storm pulses from surface runoff versus episodic pulses transmitted through limestone conduits. In this manner, aquifer dynamics and contaminant transport could be characterized, as could monitoring schedules.

On June 28, 1995, during a period of low flow, the total discharge of the Onesquethaw Creek 76 m (250 ft) downstream of the Hollyhock Hollow staff plate was gauged at only 1.4 l/s (0.05 cfs; 22 gpm). This leaves little water available for assimilation of contaminants stemming from leach fields and other sources in the groundwater basin. It is likely that Onesquethaw Creek discharge is even lower during droughts (e.g., July 1995). An estimate of the peak flow at this location was made by measuring the maximum elevation of debris (2.4 m; 8 ft), surveying the channel cross section and gradient, using a Manning's η of 0.045 and utilizing the Manning equation. Peak flow of the Onesquethaw, 76 m downstream of the Hollyhock Hollow staff gauge, is on the order of 100 m^3/s to 113 m^3/s (3,500 to 4,000 cfs).

ONESQUETHAW CREEK DELTA BUILT INTO GLACIAL LAKE ALBANY

A large failing sediment bank is exposed upstream of the staff gauge (Fig. 2). It is composed of deltaic material (e.g., gravel, sand, sandy loam) in episodically well-exposed bottom set, foreset (dipping $\approx$ 20° SW), and topset beds. The elevation of the foreset/topset contact occurs near 310 ft. msl, coincident with one of the glacial Lake Albany levels cited by Dineen (1986). Some 180 m (600 ft.) downstream of Rt. 102, a massive gray clay bed with pebbles and small cobbles is exposed, also indicating lacustrine deposition.

Dineen (1986) concludes that Lake Albany is at least 14,000 years old in the Albany area. This time period is long enough for the Hollyhock Hollow Overflow Spring Cave to have formed behind a deltaic or lacustrine sediment occlusion to the original cave mouth, or both. However, the presence of a heavy, rounded glacial boulder far in the cave may indicate earlier development, when conduit discharges were greater than today due to upgradient glacial meltwater invasion.

CALCITE-CEMENTED GLACIAL DEPOSITS

Along the southwestern bank, as well as in the channel, of the Onesquethaw Creek, there are a number of exposures of either deltaic deposits or glacial outwash cemented with calcite. They have the appearance of a conglomerate or a puddingstone. The calcite was precipitated from groundwater seepage from the adjacent limestone bench. Degassing of carbon dioxide from surfacing groundwater caused supersaturation with respect to calcite. Lithification of this conglomerate occurred post glacially.

THE BOULDER ZONE AND THE RISE OF THE ONESQUETHAW

Some 300 m (1,000 ft) upstream of the staff gauge, the gradient of the stream increases sharply. This zone of 111 m (365 ft) is armored with large boulders. A short distance upstream, at The Boil, and immediately downstream of some small fault bend folds that indicate the presence of a basal thrust fault, the Manlius streambed strikes to the NNE and dips between 8° and 12° SE. Thus, the steep gradient of this stream reach may be structural in nature. The unusually high abundance of boulders in this reach, rather than at its base, may reflect a reduction in stream power (during a period of high discharge glacial meltwaters) coincident with the surface of glacial Lake Albany.

A spring zone, composed of ten or more springs (Fig. 2), issues from the southwestern stream edge within the boulder zone. A combination of the factors discussed above has resulted in groundwater surfacing here. Some of these springs continue to flow during extremely dry periods, even when the streambed upstream is dry for over 1 km. Although groundwater tracing is required for verification, this spring zone almost certainly comprises the resurgence of the pirated Onesquethaw Creek (see Creekbed Upstream Of The Boil below), making it The Rise of the Onesquethaw.

THE BOIL

A boil of water rises in the Onesquethaw Creek just upstream of The Boulder Zone (Fig. 2). The boil fountains above creek level to approximately 0.3 m (1 ft) during periods of moderate flow. The source of the upgradient water remains to be traced. We believe that it is the outlet for upstream water that sinks into fractures and bedding planes, perhaps in an area of exposed and lithified mud cracks. Alternately, the source of The Boil's hydraulic head may be the carbonate aquifer to the north. Thin-bedded Manlius limestone can be seen along the edge of the creek just downstream of The Boil.

CREEKBED UPSTREAM OF THE BOIL

The bed of the Onesquethaw Creek upstream of The Boil, for approximately 1 km (0.7 mi), carries water for only part of the year. A similar situation occurs upstream of Clarksville, where the Onesquethaw Creek loses all its surface flow seasonally into the Onondaga Limestone (Rubin, 1991a and this volume). During drier periods, all surface flow is pirated into solutionally enlarged joints and bedding planes in the streambed. Far upstream, large and deep fissures in the limestone funnel surface water into the subsurface. The farthest downstream point of water infiltration is a function of fracture and bedding plane enlargement and their hydraulic efficiency, the number of fractures integrated with the conduit system, and the discharge of the creek. Obviously, the location of stream gauging activities must be selected with knowledge of the karst hydrology.

Following the piracy of surface waters, groundwater flow then occurs through conduits (i.e., caves) until its hypothesized resurgence down-dip at the spring zone referred to above as The Rise of the Onesquethaw.

THE PEDESTAL AND MELTWATER CHANNELS

The best of several examples on the New York Audubon property, this stream-lined and smoothed pedestal is believed to be physically contiguous with the underlying bedrock, being apparently attached and dipping approximately 5°SE. It stands some 2.4 m (8 ft) above the surrounding topography, appearing to be an erosional remnant. We hypothesize that the base of an ice sheet rested on top of this pedestal with meltwater coursing against its base and nearby in sub-parallel meltwater channels. Note the smoothed, rounded and gently sloped base and northern face that is interpreted as being worn by subglacial meltwater.

A number of shallow relict channels stand tribute to widespread and substantial subglacial meltwater flow throughout Hollyhock Hollow and much of the surrounding area. Dineen (1986) describes stagnant ice associated with the Schoharie ice margin as riddled with tunnels that drained into glacial Lake Albany. Similar tunnels related to Dineen's Alcove ice margin, the Delmar margin, or meltwater flows under glacier ice at different times apparently drained meltwater southeast off the Helderberg Escarpment. These overland flows may account for the extremely thin soil mantle present.

RIENOW SWALLOW HOLE

The Rienow Swallow Hole is located approximately 0.6 km (2,000 ft) north of the Hollyhock Overflow Spring Cave. The karst hydrology of the aquifer indicates that the Rienow Swallow Hole is physically connected to the Hollyhock Hollow Overflow Spring Cave via a conduit, being situated upgradient of the sump currently stopping exploration. Snowmelt and intense storms provide local runoff that flows into this swallow hole.

Excavation and examination of this swallow hole and debris fill provide valuable insight into the paleohydrologic flow dynamics once operable here. Moderately rounded quartz sandstone and gneiss cobbles and boulders in the clay fill denote glacial transport from the north. Well-defined, solutionally carved walls within the Rienow Swallow Hole provide evidence of paleoflow conditions no longer active today. Small scallops (solutional pockmarks) present near the base of the northwestern bedrock wall provide definitive evidence that turbulent water once flowed rapidly into the sinkhole and into a shaft or passage capable of receiving this water and bringing it into the underlying carbonate aquifer. Palmer (1991) documents that conduit enlargement requires a minimum of 5,000 to 10,000 years; thus the flow conditions necessary to produce the observed scallops were present for an extended period of time. The invasion of glacial meltwaters may have substantially enlarged a preglacial cave system that was already graded to the Onesquethaw Creek base level.

Determination Of Paleoflow Into The Rienow Swallow Hole

Measurement of scallop wavelengths may be used in the calculation of paleo and recent flow velocities and discharges (Blumberg and Curl, 1974 and Curl, 1974). A number of scallops were measured (ranging between 3.6 cm (0.12 ft) and 5.5 cm (0.18 ft) in length) along with the dimensions of the solutionally enlarged walls. This information was then assessed in order to estimate the flow conditions present at the time of formation. In order for the scallops to form in the base of the Rienow Swallow Hole, unrestricted flow must have occurred into the subsurface. Blumberg and Curl (1974) derived a universal constant for the scallop Reynold's number used in these calculations, based on plaster model studies, of 2200. Rubin (1991a), based on research specific to limestone in nearby Clarksville Cave, determined that the scallop Reynold's number may actually not be a constant, but instead may best be characterized by a range of values. Empirical observation of the flow dynamics in Clarksville Cave, coupled with characterization of flood-return intervals within the catchment basin, suggest that a scallop

Reynold's number on the order of 3300 might best fit the cave-specific conditions. Using a scallop Reynold's number of 3300, the paleo flow velocity and discharge into the Rienow Swallow Hole were determined to be on the order of 1.7 m/sec (5.6 ft/sec) and 0.7 m^3/s to 1.6 m^3/s (26 to 55 cfs), respectively (Rubin, 1994b).

The quantity of water flow indicated by Rienow Swallow Hole scallops is roughly equivalent to the maximum estimated discharge at the Hollyhock Hollow Overflow Spring. This indicates that the combined paleoflow from throughout the catchment basin was much greater during periods of glacial melting than today.

Excavation of the southern end of the Rienow Swallow Hole revealed a lens-shaped shaft extending some 2 m (7 ft) to loose fill. The central long axis of the shaft is $\approx$ 0.8 m (2.5 ft), with a short axis central width of $\approx$ 36 cm (14 in). Immediately north of this shaft, a 13 cm (5 in) wide solutionally enlarged joint opens to an underlying room or passage. White calcitic flowstone within and near this shaft was deposited by infiltrating meteoric waters after massive inflows ceased. This shaft may one day provide access into the Hollyhock carbonate aquifer.

Even greater flows are indicated by scallops present in a bedrock edge at the southern end of the Rienow Swallow Hole. The scalloped edge occurs near the top of the sinkhole, indicating periods of excessive flows when the discharge into the sinkhole and receiving cave could not handle the quantities of water present. At these times, turbulent water apparently poured into the swallow hole, partially cascading over this edge and downhill toward the Onesquethaw Creek.

Speleothem Recovery From Excavated Fill In The Rienow Swallow Hole

Excavation of sediment and rock debris from the Rienow Swallow Hole revealed numerous broken speleothems. Initially, this was thought to be evidence for a former cave entry point here, with the formations being indicative of vandalized and discarded material from within the cave. However, further excavation found speleothems, at random angles, within hard-packed clay and beneath $\approx$ 550 kg (1200 lbs) limestone blocks. The clay packing against speleothems clearly exceeds 55 years of natural packing of infilled debris.

These speleothems denote a complex geomorphic history, all within this small, but significant, swallow hole. The types of formations found include much finely-layered flowstone, small stalagmites, stalactites, and varieties formed in supersaturated pools. The bottom portion of a broken stalagmite measuring $\approx$ 30 cm (1 ft) wide at its base, 23 cm (0.75 ft) high, and with an upper diameter of $\approx$ 12 cm (0.4 ft) was recovered. This specimen reveals a history of forming on an inclined mud slope (in air-filled cave passage), incorporation of a fragment of flowstone into its structure during formation, and solutional dissolving of its center sometime after formation. Other smaller recovered specimens reveal central drip holes surrounded by concentrically layered calcite through which water flows to form stalactites. These broken speleothems formed in a cave environment.

Broken speleothems within the now collapsed cave passage provide evidence for variable paleoflows and climatic conditions, as well as multiple glaciations. One 20 cm^2 (8 in^2) sample reveals a cave history of 1) open, unrestricted water influx for at least 10,000 years and development of a short bedrock-roofed cave passage, probably from glacial meltwaters and responsible for scallop formation; 2) cessation of water responsible for conduit formation, perhaps during an interstadial period; 3) flowstone deposition over red clay fill within a cave passage; 4) formation of small stalagmites; 5) deposition and buildup of flowstone around the stalagmites; 6) crystalline growth in lily pad patterns in a small calcite-supersaturated pool (requiring a lengthy and extremely stable cave environment); 7) passage collapse and infill, probably due to glacial loading and the rapid influx of stream-borne sediment.

This sample was found in a vertical position in hard-packed clay. Another sample, possibly from a drapery-like formation, has truncated flowstone layers, with subsequent deposition, revealing a series of at least four erosion phases. Growth of this sample may have been halted by cold phases associated with various glacial periods. ^{230}Th/^{234}U dating of this sample may date interglacial and interstadial periods. Steadman's (pers. comm.) 27,350 ± 750 yrs BP ^{14}C age on a wood rat bone sample excavated from a Clarksville area cave may 1) closely limit the maximum age for the initial advance of the late Wisconsinan ice margin, and 2) correlate with an interstadial speleothem erosional phase.

WILTSIE'S CAVE

Even short caves can provide valuable information that can be used to reconstruct the geomorphic history of an area. The entrance to Wiltsie's Cave lies approximately 60 m (200 ft) north of the Rienow Swallow Hole, and also probably served as a swallow hole for glacial meltwaters (Fig. 3). The large size of this relict cave, now receiving only small quantities of local surface runoff and infiltration, further supports the formation or enlargement by subglacial meltwater invasion argument. The cave descends as a joint-aligned (S32°W) vadose canyon, with ceiling heights and passage widths up to 7.6 m (25 ft) and 3 m (10 ft), respectively. Flowstone covers much of the walls. The passage descends in a series of steps through several chert beds in the upper portion of the Coeymans Limestone and down into the Manlius Limestone. Near the cave's southwestern end, and perhaps 12 m (40 ft) below the ground surface (not surveyed), the rectangular passage cross section changes to a keyhole shape. The top tubular portion of this keyhole-shaped cross section may reflect the elevation of a former water table in the aquifer. Figure 3 shows the distinct change in passage trend (to S13°W) toward the southwestern terminus, aligned with the strike of the bedrock. Palmer (1991) established that groundwater flow in the vadose zone is controlled by bedrock dip (with localized joint control), and follows strike in the phreatic zone. Southwestern continuation of this passage is blocked by flowstone, but a narrow joint some 12 m (40 ft) northeast of the flowstone occlusion, drops vertically to a small stream that flows at the base. Assuming that the short section of tubular passage (i.e., the top portion of the keyhole), does reflect a former water table; the deep solutionally-enlarged joint represents stream piracy to a new and lower base level.

Efforts by Nick Viscio and others to extend this cave beyond the base of its southwestern pit and into the larger portion of the carbonate aquifer in the late 1970s did not meet with success. The entrance to the cave was physically closed in 1984.

OTHER KARST FEATURES IN THE GROUNDWATER BASIN

Other small caves and karst features within the carbonate hydrologic unit provide information on relict and active flowpaths within the epikarst. These include a number of very large sinkholes present within the groundwater basin. Some have deep solutionally enlarged joints that provide infiltration pathways into the epikarst and underlying carbonate aquifer. Many are situated north and north-northwest of Hollyhock Hollow in a limestone area of about 13 km² (5 mi²). This area contains many karst features too numerous to discuss here. However, some mention of the significant ones is warranted.

Two small caves are known north of Hollyhock Hollow, Hole in the Wall Cave and Brokendown Cave. The former is a small cave located about 1,950 m (6,400 ft) north of the overflow spring in a large limestone quarry north of Albany County's filtration plant. This is the "Quarry Near Feura Bush" of Marshak (1990). Hole in the Wall Cave, a small relict cave, is exposed high up on the quarry's southern wall. The cave formed in the Manlius Limestone and served as a vadose infeeder to a downgradient segment of a larger cave system. The initial passage trend is S24°W. The passage averages 0.6 m (2 ft) wide and 0.9 m (3 ft) high for approximately 2.7 m (9 ft) before turning to the

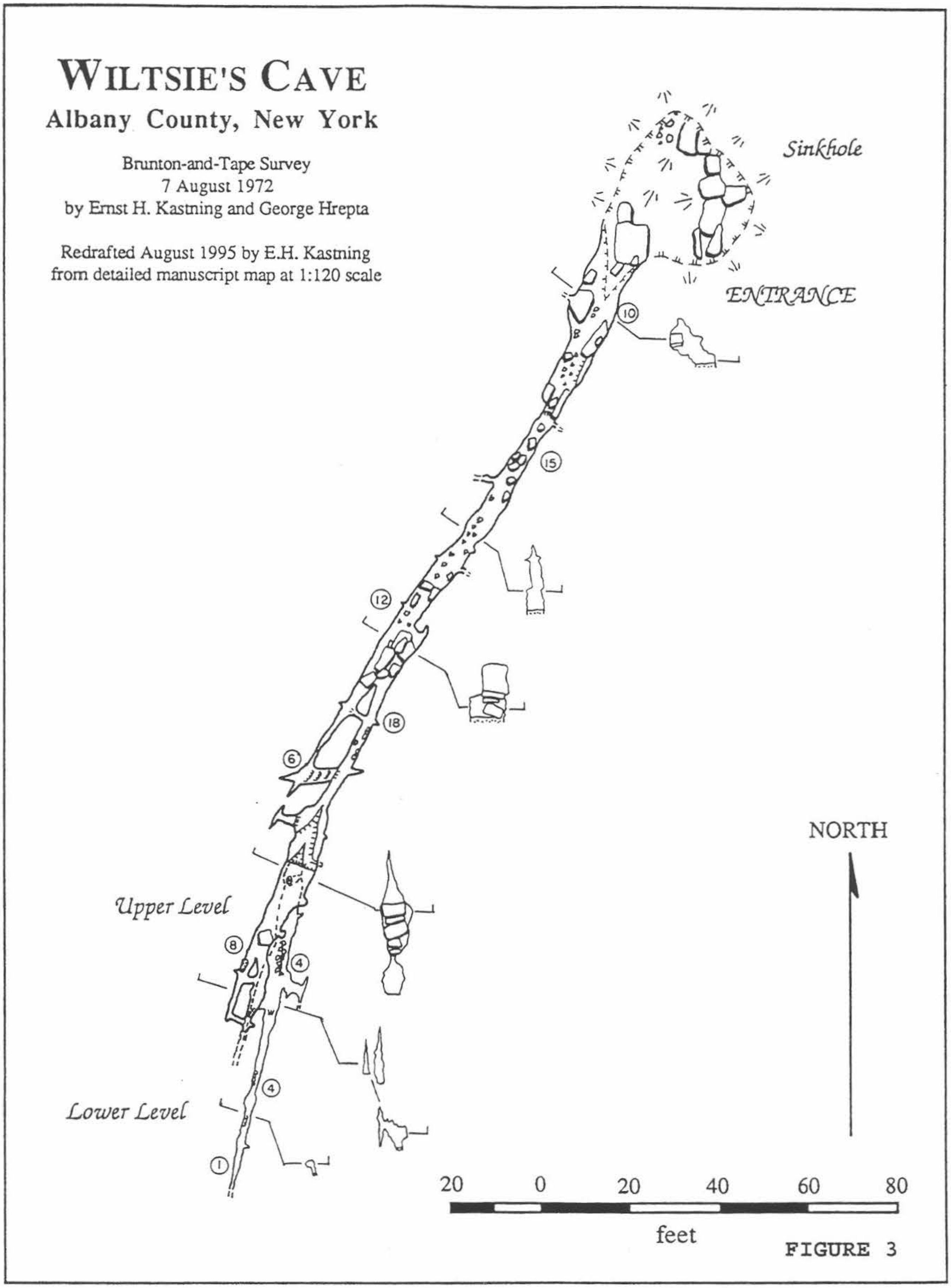

WILTSIE'S CAVE
Albany County, New York
Brunton-and-Tape Survey
7 August 1972
by Ernst H. Kastning and George Hrepta
Redrafted August 1995 by E.H. Kastning
from detailed manuscript map at 1:120 scale
Sinkhole
ENTRANCE
10
15
12
18
6
Upper Level
8
4
4
Lower Level
1
NORTH
20
0
20
40
60
80
feet

FIGURE 3

southeast. A calcite mineralized bedding fault is present in the cave, but it did not control passage development.

Brokendown Cave is located about 370 m (1,200 ft) south of Hole in the Wall Cave in the base of a small sink in a large shallow depression. The cave is morphologically complex and contains about 75 m (250 ft) of passage. It is formed along two (2) parallel joints with connections between the joints at two or more levels. Overall, the cave gives the impression of a vertical maze.

About 600 to 1,200 m (2,000 to 4,000 ft) west of Brokendown Cave and 1,500 to 2,300 m (4,900 to 7,400 ft) north of the overflow spring are three large closed depressions. Each of these receives runoff from outside the topographic limits of the depressions. The western-most of these sinks is said to contain a 12 m (40 ft) deep pit called Dribblemouth Pit. Efforts to find this pit in 1993 and 1994 proved unsuccessful. The depression with the largest drainage area is the northern-most one.

About 3,200 m (10,500 ft) north-northwest of the overflow spring is an occluded lateral insurgence near the base of the Helderberg Escarpment. Little is known about this feature due to access difficulties. The lack of resurgences in the immediate vicinity seems to indicate that water sinking here is flowing down-dip to the southeast. It may represent one of the farthest up-dip recharge points for the Hollyhock carbonate aquifer. About 450 m (1500 ft) west of this insurgence is a small cave called Tin Can Cave. It is at the bottom and on the south side of a closed depression about 11 m (35 ft) deep and 150 m (500 ft) in diameter. The cave is fed by a small lateral insurgence with a limited drainage area.

AQUIFER CHARACTERISTICS AND EVIDENCE FOR CONDUIT PATHWAYS FROM WELLS

Data obtained from well drilling in the area provide information on the nature of the carbonate aquifer. A number of wells have produced little or no water, often causing property owners to drill numerous wells. Wells along Rarick Road in fractured limestone are reported to have yields of approximately 0.1 l/s (2 gpm), with one yielding in excess of 0.6 l/s (10 gpm) (Banahan, pers. comm.). Some property owners along Rarick Road report sulfur water, probably stemming from pyrite in the Snake Hill shale.

Two wells in close proximity, situated approximately 600 m (2,000 ft) northwest of the New York Audubon headquarters building, penetrated approximately 6 m (19 ft) of "mason sand" and 29 feet of limestone prior to penetrating two foot conduits filled with sand. Banahan (pers. comm.) reports yields in excess of 0.6 l/s (10 gpm) from these conduit wells. Sand filling of this or these conduits indicates pre-Holocene formation with infilling by deltaic sands, perhaps those that only a short distance to the southeast formed a delta into glacial Lake Albany.

Another exception to problems found obtaining water in the aquifer is the New York Audubon headquarters building well (situated in the parking lot area). The well is 16 m (54 ft) deep with a static water table of 12.87 m (42.22 ft) below the top of casing on June 28, 1995. Analysis of a short-term (160 minute) pumping test conducted on the aquifer (using the Theis nonequilibrium well equation and type curves) indicates an aquifer transmissivity on the order of 110 m^2/d (9,000 gpd/ft), enough to provide a small municipality with water. Assuming no hydraulic boundaries are encountered during longer-term pumping, this well may be capable of providing a sustained yield of 300 m^3/d (55 gpm; $\approx$ 79,000 gpd). A log of the well is not available, but it may be inferred that it is completed in 1) the highly fractured Manlius Limestone below the elevation of the cave system; 2) deltaic and glacial sediments present in a shallow incised and filled bedrock-flanked channel of the Onesquethaw Creek; or 3) a segment of the lower end of the cave system, backflooded behind the now sediment-occluded cave mouth. Another well on New York Audubon property, situated approximately 120 m (400 ft) to the northwest, at approximately the same surface elevation, is 10 m (32 ft) deep, with a water table at 6.80

m (22.32 ft) below the top of casing. Groundwater in this well probably flows through the fractured Manlius Limestone to either the Hollyhock Overflow Spring Cave or directly to the Onesquethaw Creek.

Five wells were drilled to depths of 49-67 m (160-220 ft) around Wiltsie's Cave in an effort to find water for Hereford cattle (Banahan, pers. comm.). Occasional voids up to 0.15 m (0.5 ft) were found prior to reaching the black, middle Ordovician, Snake Hill shale (designation of Isachsen et al., 1991) between 34 and 37 m (110 and 120 ft) below ground surface. Not surprisingly, groundwater was not found in randomly drilled wells in the Coeymans and Manlius Limestones, as groundwater converges in karst settings toward conduits where the hydraulic head is lowest. Quinlan and Ewers (1985) have estimated the odds of encountering a dissolutional conduit in a karst aquifer by drilling a well at about 1:2600. If access to the cave system and its stream are gained through either the Rienow Swallow Hole or Wiltsie's Cave, a productive well location will be radio-located.

Drilling by Banahan (pers. comm.) northeast of Wiltsie's Cave revealed a 1.7 m (5.5 ft) conduit (i.e., cave passage) with in-washed gravel in limestone at a depth of 16 m (52 ft) below the ground surface. This well has continuously supplied water to his barn since 1983, except under drought conditions when groundwater tributary to the well temporarily ceased flowing for 16 days in July 1995. Two other carbonate wells situated within approximately 120 m (400 ft) south of the barn conduit well encountered sediment plugged conduits from 15 to 17 m (50 to 56 ft) below the ground surface. This plugged conduit(s) provides evidence for either 1) a now abandoned segment of a cave system within the Hollyhock carbonate aquifer that carried groundwater sometime prior to the most recent deglaciation, or 2) a partially sediment occluded, but still functional, conduit that carries groundwater alongside sediment fill. An attempt to flush and blow out these sediments failed. The elevation of this conduit (the more likely situation) or conduits may coincide with the Manlius/Coeymans contact.

The location of the conduit or conduits found in these three wells may imply that subsurface drainage trends further down-dip (4-14° SE) and southeast of Wiltsie's Cave and the Rienow Swallow Hole prior to encountering a structural barrier or fault plane that shunts groundwater flow southwest to the Hollyhock Hollow base and overflow springs. Northward projection ($\approx$ N21°E) of the steeply dipping thrust fault along which the Hollyhock Hollow Overflow Spring Cave formed places it somewhere near these wells. This suggests that either 1) the 50^{+}°NW dipping limestone beds of the fault's footwall form a structural barrier to southeastern groundwater flow, and/or, 2) as observed in the Hollyhock Hollow Overflow Spring Cave, groundwater flow and conduit development occurs preferentially along the thrust fault plane and associated fractures.

PALEOCLIMATE

Evidence was found documenting that the Hollyhock carbonate aquifer formed prior to the late Wisconsinan (prior to ca. 24,500 yr B.P.; Miller and Calkin, 1992) Woodfordian ice advance. The history portrayed in the Rienow Swallow Hole and Wiltsie's Cave provides evidence that the Onesquethaw Creek channel and regional drainage patterns were adjusted to today's base level prior to cave formation and glacial modification. Interpretation of physical features within the Hollyhock Hollow Sanctuary suggests that a cave system formed in pre-Woodfordian time and was subsequently enlarged by subglacial meltwater invasion. The lengthy time (at least 10,000 years) required to enlarge fractures into conduits, such as in the Rienow Swallow Hole, argues for long-term seasonally warm (above 0° C) climatic conditions. Perhaps these conditions occurred during recessional stages of glaciation. Cave enlargement is interpreted as occurring under subglacial conditions, when a very different flow regime was present. Seasonal meltwater beneath glacier ice may have flowed down a series of bedrock troughs and into several swallow holes as it drained toward the already well-adjusted Onesquethaw Creek.

The pedestals, scallops in the Rienow Swallow Hole and Wiltsie's Cave, and meltwater channels provide evidence for widespread and long-term surface water flow throughout the Hollyhock area. The present catchment is not sufficient to provide the required water quantities. A physically enlarged glacial ice catchment is inferred, with large seasonal flows under warm based ice. Even the minimum rates of cave development, for caves requiring water from beyond the physically available catchment (i.e., from under glacial ice extending to the northwest), argue for extended periods of seasonal warmth during glaciation. Similar seasonal variations occur today in Castleguard Cave that extends under the Columbia Ice Field in the Canadian Rockies.

Speleothems recovered from sediments in the Rienow Swallow Hole provide evidence for cessation of glacial meltwater inflow for extended periods during interglacial or interstadial periods. Dryer physical and climatological conditions permitted stalactite, stalagmite and flowstone formation in this shallow cave passage. Several erosion phases are indicated by truncated flowstone growth and the incorporation of a broken flowstone fragment into another speleothem. ^{230}Th/^{234}U dating of speleothems may elucidate the geomorphic chronology.

LAND USE CONSIDERATIONS

Carbonate aquifers and their receiving streams (i.e., the Onesquethaw Creek) are very sensitive to contaminant inputs and require special land use consideration. Carbonate aquifer hydrology is very different from porous media (i.e., soil) and fractured bedrock aquifers with slow laminar groundwater flow, instead being characterized by rapid non-Darcian (i.e., turbulent; non-laminar) subsurface flow through conduits (i.e., caves) with no natural filtration of contaminants. In the classification of carbonate aquifers of Quinlan et al. (1992), the vulnerability or susceptibility of field trip karst aquifers to groundwater pollution is hypersensitive.

Whereas subdivision and development within karst basins has historically occurred on an individual application basis, a more broad-based master planning process is needed to maximize protection of groundwater and surface water resources. Planning in environmentally sensitive areas should take into account the likely cumulative contaminant loading into the karst system, and a reasonable measure of it and its receiving stream's assimilative capacity. The development of an area must be within the natural constraints of its geology and hydrology (Rubin, 1990, 1992, 1994c, 1995).

Knowledge of flow dynamics in the epikarst is critical in land use planning above hydrologically sensitive carbonate aquifers. Surface runoff and infiltration into Wiltsie's Cave and the Rienow Swallow Hole (relict caves no longer receiving the water responsible for forming them) verifies the integration and continuum of groundwater flow between relict and deeper, higher discharge drainage routes. Thus, solutionally enlarged fractures and relict caves and swallow holes in the groundwater basin are integral, functioning components of the epikarst, funnelling runoff and infiltrating meteoric waters to deeper conduit flow routes.

Significant quantities of waste water and other contaminant additions to Albany County carbonate aquifers may contribute to groundwater and surface water degradation. Because the Hollyhock carbonate aquifer has 1) little or no soil-mantle; 2) a well-developed epikarst; 3) an efficient carbonate aquifer; 4) much of its drainage basin (and thus its contaminant assimilative capacity) beheaded at the Wolf Hill Dam; and 5) an influx of periodic nutrient, pesticide, and pathogen additions from the stressed and threatened Helderberg Lake, it is worthy of special land use and, ultimately, zoning consideration. We recommend that long range plans for development for this area not be adopted until the karst hydrology present is further investigated, critical area maps are made available, and potential downgradient impacts are addressed.

INTRODUCTION: JORALEMON PARK

At Joralemon Park and vicinity, entrances to active (Hannacroix Maze and Merritt's Cave) and relict (Joralemon's) caves will be visited. Damming of a former surface drainage route by glacial sediment, as well as erosional derangement of surface streams, have resulted in the enlargement of the Hannacroix Maze floodwater cave. All surface flow from throughout the basin is deranged from an earlier flow route and is now pirated through Hannacroix Maze. Prior to deposition of the sediment dam that now forces surface water from throughout the basin to be pirated through Hannacroix Maze, surface flow occurred through Joralemon's Cave. Nardacci (1994) has documented much of the karst hydrology of this stop.

JORALEMON PARK LOCATION

The Hannacroix Maze karst is located along Route 102, slightly northwest of the village of Ravena, Albany County, New York (see Fig. 8 and Road Log). A portion of the study area occupies a section of Joralemon Park, owned by the Town of Coeymans.

GEOLOGY

Three rock units outcrop in Joralemon's Park. All cave development has occurred in the fossiliferous, light bluish-gray Onondaga Limestone. The Onondaga is subdivided into subunits based on the presence or absence of black chert beds. Fracture enlargement and conduit development occurs in all subunits, but the more massive chert-free subunits tend to exhibit larger conduit development. Chert beds sometimes temporarily perch groundwater flow until a fracture ultimately permits downward flow into a less cherty subunit. Cave development in the Onondaga Limestone proceeds through all subunits, with the possible exception of where the hydrologic base level lies above the base of the unit. The Onondaga Limestone is recognized as one of the best cave-forming rock units in New York State.

The Onondaga Limestone is underlain by a thin bed of the Schoharie Formation which is a silicious, clay-rich, dolomitic limestone and a poor cave former. It is dark bluish gray in color, weathering by solution of the lime into a brown porous sandstone. This unit may serve as the base level control for downward cave formation in Joralemon Park. The Schoharie Formation is underlain by the thick, impermeable Esopus Shale. The Esopus is composed of dark brown to black shale and siltstone. It is often recognized in exposures by the *Zoophycus* trace fossil that resembles a rooster's tail. The Schoharie Formation and the Esopus Shale belong to the Lower Devonian Tristates Group.

The Tristates Group lies stratigraphically above the Helderberg Group. The lowest two units of the Helderberg Group, the Manlius and Coeymans limestones, were observed at the Hollyhock Hollow Sanctuary.

HANNACROIX MAZE

Hannacroix Maze (Fig. 4) is developed in the lower subunits of the Onondaga limestone above the contact with the Schoharie Formation. It is a low, wet network of joint-controlled passages (Nardacci, 1994), presenting a classic example of Palmer's (1975) floodwater maze. A detailed map of the area (Fig. 5) shows a sediment ridge preventing the small stream and runoff in the area from flowing freely to the south, resulting in water ponding to the northeast of Hannacroix Maze. While there is no dramatic elevation change as surface water flows south, it is funneled into a relatively narrow valley at the foot of which is the ridge containing Hannacroix Maze and, farther south, Merritt's Cave. Hence, during floods water has sufficient head to be injected into all available joints, thus producing a maze pattern.

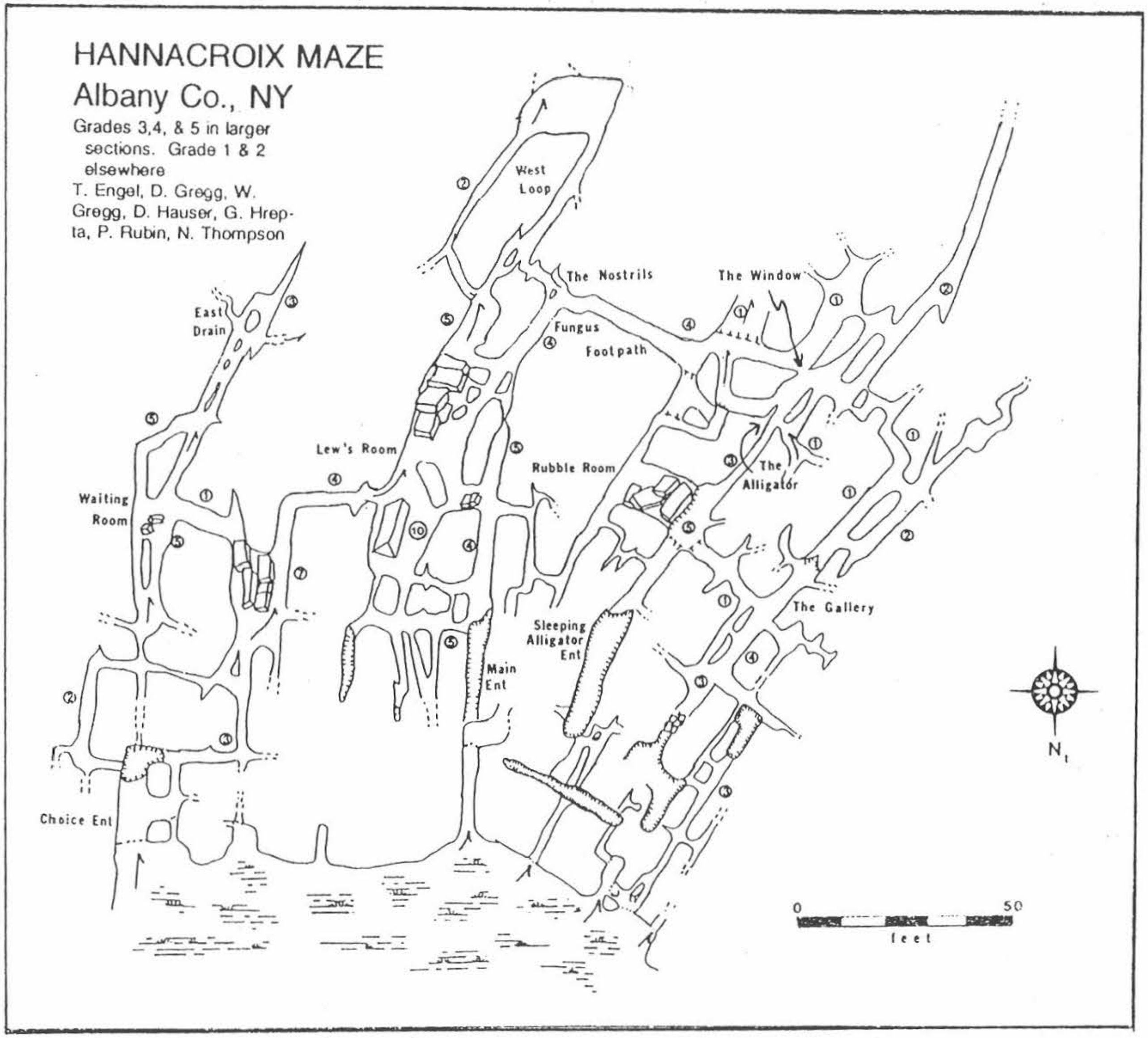
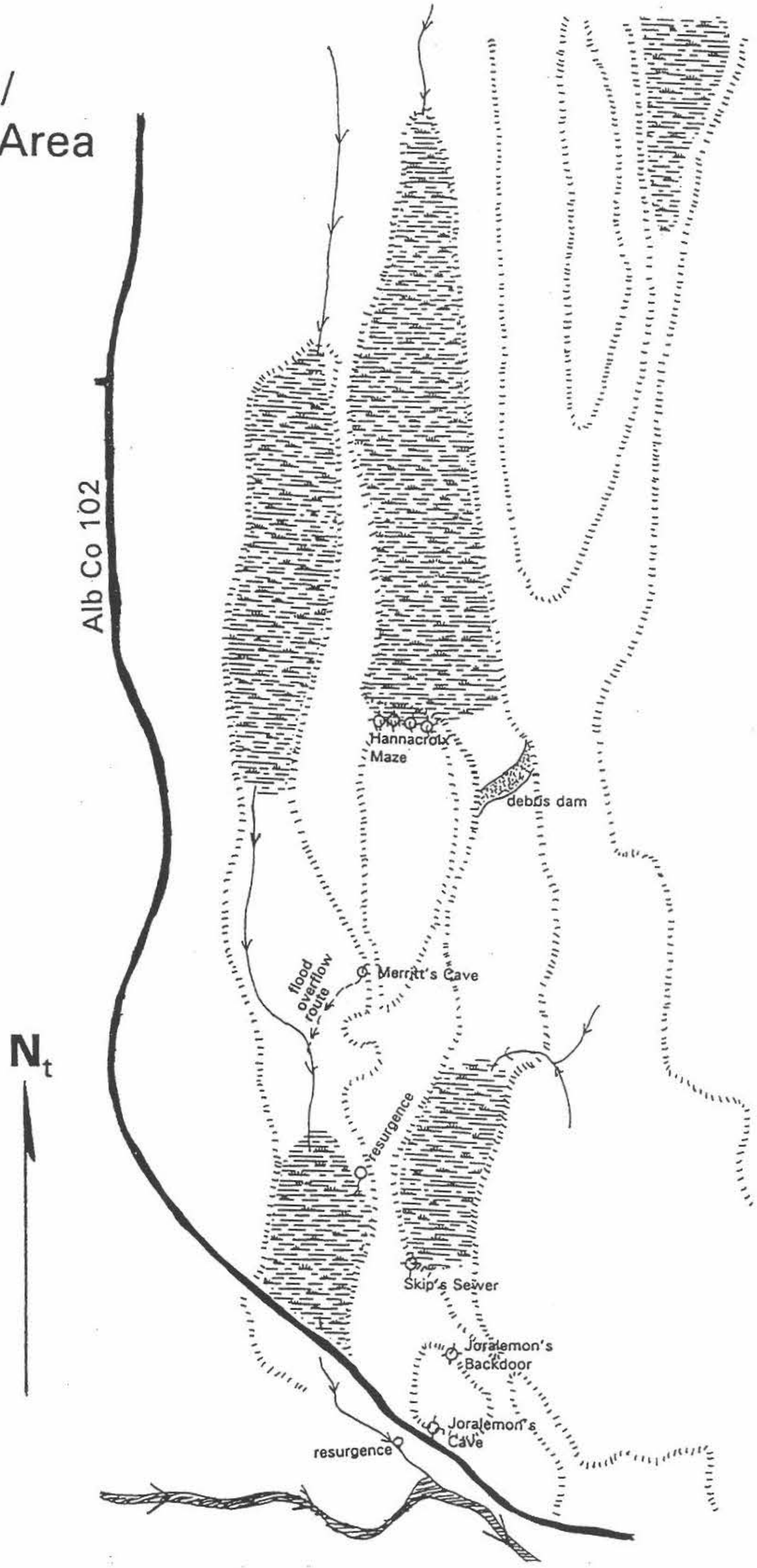


Figure 4 - Hannacroix Maze

Figure 5 - Joralemon's/ Hannacroix Area



Although the passages of the cave are small - with heights frequently less than one meter and their widths rarely exceeding that - there is evidence for turbulent flow during floods. Scallops on the walls commonly show lengths of less than 5 centimeters (2 in), and huge quantities of flood-borne organic debris such as bark, tree limbs and leaf fragments are found in the extremities of the passages and jammed into ceiling fissures.

Most of the development and enlargement of Hannacroix Maze probably occurred during and after Woodfordian glaciation. Deposition of the small sediment ridge southeast of the Hannacroix Maze insurgence area may have occurred during Woodfordian glaciation, since most surficial soils reflect the most recent glacial processes. A minimum of 14,700 years (following retreat of Woodfordian ice) (DeSimone and LaFleur, 1985) have been available for cave enlargement and perhaps more if subglacial meltwaters also contributed to enlargement of the pre-existing fracture network. Evidence of such subglacial meltwater flow is provided by Dineen (1986), Rubin (1991b and this volume), and at the Hollyhock Hollow Sanctuary (this paper). Both Woodfordian and Holocene enlargement of Hannacroix Maze and Merritt's Cave is more likely than solely post-glacial development because solutional cave formation requires a minimum of 10,000 years (Palmer, 1991) before passageways obtain sufficient size for human entry. Additional passage cross-sectional size requires additional time. Holocene climatic conditions have resulted in frequent seasonal flooding of the cave system. Both Hannacroix Maze and Merritt's Cave usually flood annually.

The age of the cave has not been determined, although ^{230}Th/^{234}U disequilibrium series dating of speleothems may help establish a minimum date of formation. Reconnaissance to date has not revealed allochthonous glacially-derived sediments, but they may be present under the surficial ooze. Furthermore, the presence of such deposits may simply signal Holocene inwashing.

MERRITT'S CAVE

Merritt's Cave, like Hannacroix Maze, has not yet been full explored and surveyed. It almost certainly connects with Hannacroix Maze. Like Hannacroix, it is a maze cave, although its entrance resembles a talus cave. On this western edge of the ridge, numerous boulders have slumped and been moved by glacial ice from the bedrock, creating numerous false entrances and squeezes that obscure the actual entrance to Merritt's Cave. One section of the cave that can easily be entered is a high narrow canyon. Scallops in the walls average less than 5 cm (2 in) in length, indicative of rapid flow. Like Hannacroix, Merritt's Cave contains numerous small side passages, some of which pinch out rapidly or occlude in breakdown, and some of which may eventually be pushed by explorers to extend the cave's length. By considering the relative physical positions of Hannacroix Maze (600 m; 2,000 ft) and Merritt's Cave (275 m; 900 ft) and their lengths, there may be hundreds of meters of unentered passage in the cave system.

Merritt's Cave is a floodwater overflow spring resurgence. Water flowing out the entrance must rise about two meters. In normal flows, a small stream is seen inside the cave. This flows into an inefficient drain just inside the eastern-most entrance. In low- to moderate-flow conditions, the water resurges at an occluded spring about 240 m (800 ft) south of Merritt's. Four other occluded springs are also present in the area of this resurgence. All five springs may discharge from a single conduit. As flow increases, each successive spring to the north and elevationally higher begins to flow. During extreme flood, the highest and most northerly spring flows.

A sixth resurgence is present some 130 m (425 ft) south of Merritt's. It resembles a sinkhole in shape. At very high flow, water rises from a pool in the depression and overflows to the west.

As already noted, Merritt's Cave serves as a floodwater resurgence for Hannacroix Maze. About 15 m (50 ft) downstream of the Merritt's Cave entrance, surface flow sinks into the subsurface. At certain flows, water coming from Merritt's entirely sinks at this point. As flow increases beyond the capacity of this sink, the water flows west, then south on the surface. Of interest is a low bedrock dam at the bend in the water course. In times of very high water, water is impounded behind this dam, composed of faulted, ≈ 30° SE dipping, Schoharie Formation beds. Beyond this, the stream flows south to a tributary of Hannacrois Creek.

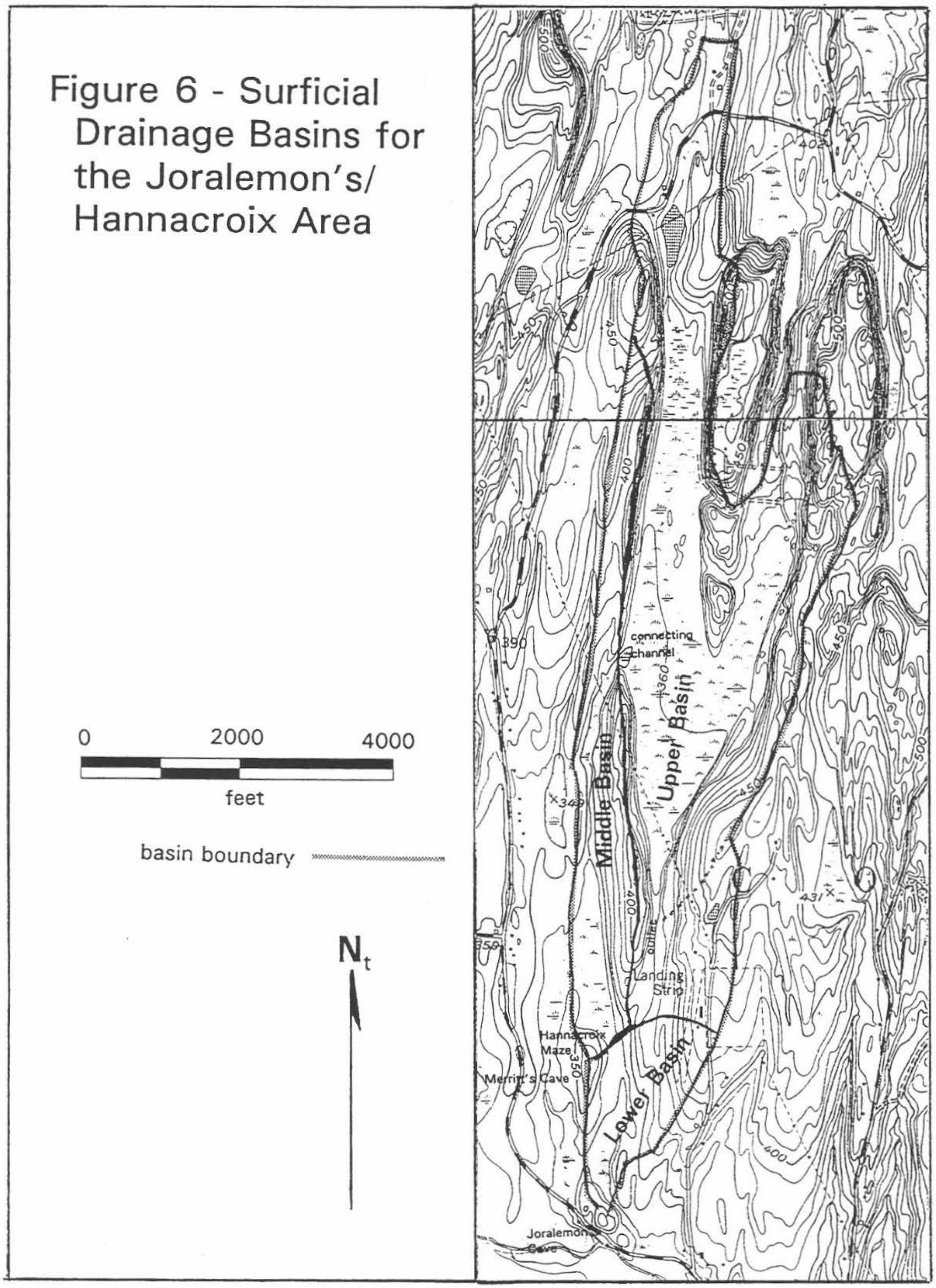
JORALEMON'S CAVE

Joralemon's Cave and Joralemon's Backdoor (Fig. 7) are of particular scientific value because together they preserve what may be the oldest remaining geologic record of the drainage patterns, base level, and rates of regional erosion present many tens or even hundreds of thousands of years ago in the Joralemon Park area (Fig. 5). The way in which their rock layers are carved tells a story of the evolution of the landscape we see today. Joralemon's Cave and Joralemon's Backdoor are two segments of a single cave, now separated by sediment. When this cave formed, water that flowed through it did so at the lowest topographic drainage level. The surface topography and drainage routes present at this time were quite different from what they are today. We believe that the limestone knoll that Joralemon's Cave formed in once extended farther to the east and west. The age of the cave's formation and downward erosion of the limestone to the east is not known. Although erosion (glacial and non-glacial) and downcutting have left it as an abandoned cave segment high up in a ridge, its physical setting was such that it once occupied a low valley. Runoff from higher elevations to the north flowed downhill until sinking into fractures and sinkholes draining into Joralemon's Cave.

Preserved in a resistant and faulted Onondaga Limestone knoll, Joralemon's Cave is a large-diameter ($6^{+}m^2$; 65 ft^2), relict cave segment partially filled to an unknown depth with sediment. It is deranged from present day drainage, much of which now flows through Hannacroix Maze and Merritt's Cave. Scallops on the walls of Joralemon's Cave provide evidence of rapid flow to the ancestral Hannacrois Creek. Using the methodology described previously (see Determination of Paleoflow into the Rienow Swallow Hole), scalloped walls in Joralemon's Cave indicate paleoflows varying between 4.2 and 10.5 m^3/s (150 and 370 cfs) with velocities of ≈ 0.7 to 1.7 m/s (2.3 to 5.6 ft/sec). The exposed cross-sectional area of Joralemon's Cave indicates active flow for a minimum of 10,000 years, possibly tens of thousands of years. Deposition of the glacial sediment dam southeast of Hannacroix Maze is believed to be a factor that resulted in the derangement of surface flow formerly draining to Joralemon's. This derangement contributed to the ultimate abandonment of Joralemon's Cave. Water-worn bear and muskrat bones excavated from Joralemon's Cave indicate Pleistocene stream-borne deposition. Holocene age bones of northern wood rat, frogs, turtles, and many other species have also been found in the cave (Steadman, pers. comm.).

Determination of the age of formation of Joralemon's Cave presents more of a challenge than the Hannacroix Maze/Merritt's cave system. Since all present drainage occurs through conduits elevationally lower than Joralemon's (i.e., Hannacroix Maze/Merritt's system) and Joralemon's Cave is deranged from today's drainage patterns, it is our interpretation that cave formation and drainage through Joralemon's Cave predates that of Hannacroix Maze. In keeping with this interpretation, the elevation of Joralemon's Cave might be used to assess a former hydrologic base level or infer development during another glacial or interglacial period. Sediment infilling in the back of Joralemon's Cave reveals that the conduit dips downward toward Joralemon's Backdoor. The last chapter in the flow history of Joralemon's Cave is recorded in the sediment infill that now floors the cave and blocks the former connection route between Joralemon's Backdoor and Joralemon's Cave, perhaps coincident with the final retreat of Altonian (pre-Woodfordian) ice from this area.

Figure 6 - Surficial Drainage Basins for the Joralemon's/Hannacroix Area



JORALEMON'S CAVE
JORALEMON'S BACKDOOR

Shown in their relative positions
Grade 5
T. Engel
F. Torncello
M. Torncello

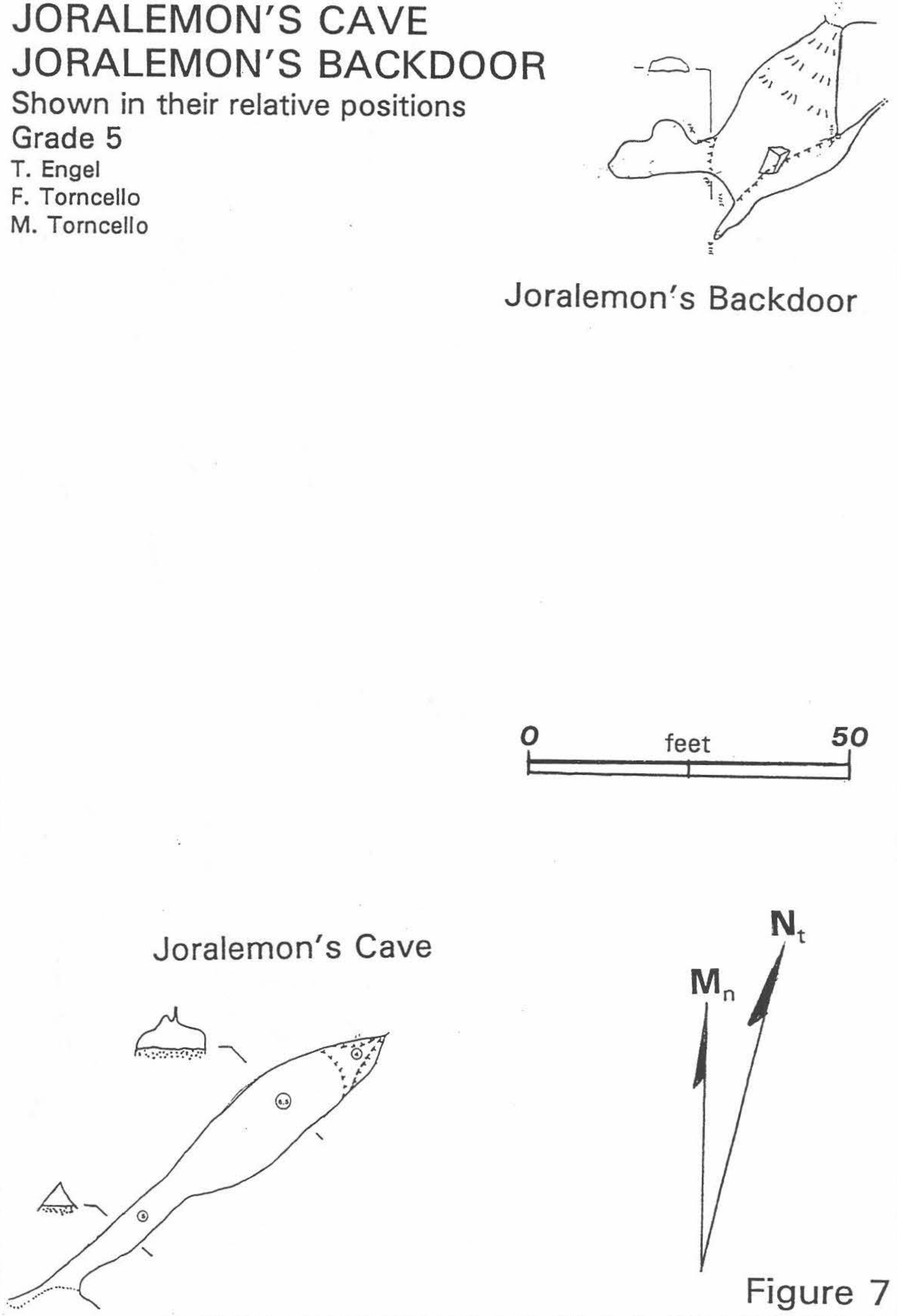


Figure 7

Development and enlargement of Hannacroix Maze and Merritt's Cave can be inferred to have occurred predominantly after the abandonment of Joralemon's Cave, perhaps with initial formation coincident with the drop in base level that ultimately led to the abandonment of Joralemon's Cave. Woodfordian glacial sediment dams block drainage east of the Hannacroix ridge (the low limestone ridge containing Hannacroix Maze and Merritt's Cave), furthering development of Hannacroix Maze and Merritt's caves. While the surface catchment tributary to Hannacroix Maze is on the order of 2.4 km^2 (0.9 mi^2) (Fig. 6), it is important to recognize that the subglacial catchment basin tributary to these caves was once greatly expanded. Thus, flow beneath warm-based ice straddling the Hannacroix Cave ridge, the Joralemon's knoll and the ridge east of Joralemon's knoll converged down to a narrow, restricted outlet area.

The rates of dissolution required to develop a conduit the size of Joralemon's Cave suggests periodic floodwaters flowed through the cave for a period in excess of 10,000 years. Furthermore, the quantities of water needed to largely fill (or at least obtain the discharges indicated by scallops) Joralemon's Cave require a drainage area larger than that available today or a greater source of water, or both. Both factors can be associated with a subglacial catchment basin. Thus, we infer that climatic conditions remained stable for thousands of years, with seasonal warming, during glaciation.

JORALEMON'S HYDROLOGIC CHRONOLOGY

There are several possible interpretations that can be put forth regarding the ordering of events that shaped the landscape we see today in the Joralemon's/Hannacroix area. We offer the following proposal.

Figure 6 shows the surficial drainage basin for Hannacroix Maze as well as a southern portion extending south to Joralemon's. For the sake of discussion we have divided the basin into three sub-basins: upper, middle, and lower.

At one time water may have flowed directly from the upper basin into the lower basin through the pass at the very southern end of the upper basin. At this time, water was flowing through Joralemon's Cave, probably aided by subglacial meltwaters. During this same time, some water was also flowing in the middle basin. However, due to the small size of this basin only a fraction of the discharge currently seen was flowing here. We believe that a small "ancestral" Hannacroix Maze formed at this time. The larger passages in this cave such as the Fungus Footpath (see Fig. 4) may have formed at this time. It is interesting to note that the major secondary carbonate deposits in the cave are found only in these larger passages.

At some later point, the upper basin ceased to flow into the lower basin. This may have been caused by glacial damming of the outlet from the upper basin some 600 m (2,000 ft) northeast of Hannacroix Maze or by stream piracy into the middle basin by headward erosion or by both. Stone walls found in the former outlet of the upper basin contain a high percentage of glacial erratics. If we assume that the material used to build these walls was from the immediate vicinity, then glacial damming seems highly likely. The sediment dam (Fig. 5) southeast of Hannacroix Maze is located at the junction of the upper and lower basins. It is approximately at 335 ft msl, an elevation of one stage of glacial Lake Albany (Dineen, 1986). The dam has likely been reworked by water that still flows during periods of high runoff.

More water in the middle basin resulted in backflooding and enlargement in both Hannacroix Maze and Merritt's Cave. Even now water levels in Merritt's may vary during the course of the year by as much as 2.4 m (8 ft).

The greatly reduced flow in the lower basin found a new outlet just north of Joralemon's Backdoor. There appears to have been a gradual headward abandonment of insurgences in this area to it's current location at Skip's Sewer (Fig. 5). This water may resurge in the pool across Rt. 102 from the entrance to Joralemon's Cave.

ACKNOWLEDGEMENTS

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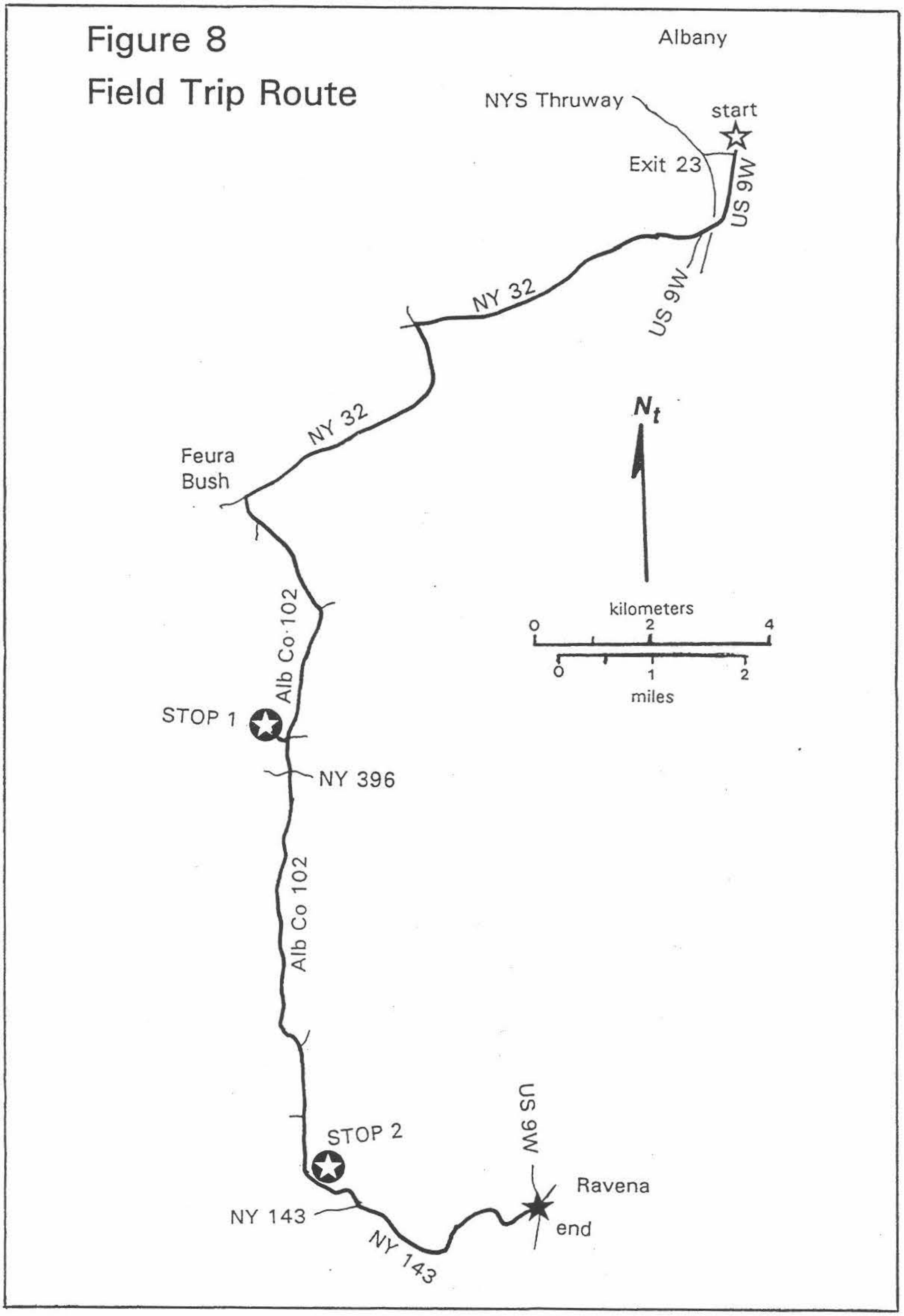
Figure 8
Field Trip Route



ROAD LOG: HOLLYHOCK HOLLOW SANCTUARY AND JORALEMON PARK

Total Miles	Miles From Last Point	Route Description (see Figure 8)
0.00	0.00	**START** - Jct US 9W and Thruway Exit 23. Proceed south on 9W.
0.45	0.45	Cross Normanskill Creek on US 9W.
0.80	0.35	Jct NY Rt 32 and US 9W. Continue south on US 9W and NY Rt 32.
1.20	0.40	Rts 32 and 9W split. Veer right on NY Rt 32.
4.45	3.25	Turn left following NY Rt 32.
6.20	1.75	Cross Vlomankill.
7.60	1.40	Turn left on Albany County Rt 102 (Old Quarry Rd.).
8.10	0.50	Exposure of Snake Hill shale behind house on right.
9.30	1.20	Feura Bush Quarry uphill and on right.
10.00	0.70	Roadcut through Coeymans Limestone.
10.70	0.70	Turn right onto Rarick Rd.
10.90	0.20	**STOP #1** - Turn left into the New York Audubon parking lot. The Hollyhock Hollow Nature Sanctuary is open to the public. Turn right onto Rarick Rd. and return to Alb. Co. 102.
11.10	0.20	Turn right onto Albany County Rt. 102.
11.30	0.20	Cross the Onesquethaw Creek.
11.50	0.20	Jct with NY Rt 396. Continue south on Rt 102.
11.60	0.10	Cross Feuri Spruyt Creek.
12.35	0.75	Esopus Shale outcrop on right side of road. Continue S on Rt 102.
15.20	2.85	Large rock of Onondaga Limestone on right.
15.80	0.60	Joralemon Park tennis courts on right.
16.15	0.35	**STOP #2** - Pull off of Rt 102 into area on right. This is a Town of Coeymans park. Continue south on Rt 102.
16.65	0.50	End Albany County Rt 102. Turn left onto NY Rt 143.
19.15	2.50	**END** - Jct US 9W and Rt 143. Start of field trip is about 12 miles north on Rt 9W.