Surficial Geology Mapping + Geohazard Identification + Coastal Zone Mapping = Better Land-use Planning in Central Antigonish County

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Introduction

Bedrock and surficial materials underlying our homes, businesses and infrastructure are often forgotten when communities make land-use decisions. This could be a minor or major oversight, but certainly not an intentional one. Geology, the study of rocks, minerals, surficial materials and their interactions with society, is given little attention in the provincial education system. Students graduating from high school and entering university to become land-use planners have never been taught the basic concepts of geology so it should not be a surprise when bedrock and surficial materials are not considered in the planning process.

What does this oversight mean to a community? If the chosen development site happens to be underlain by gypsum karst it will be major issue. In this example, finding a source of potable water will be the first challenge, unless municipal water supplies are available to the community. The second one could be filling in a giant sinkhole that appeared overnight and swallowed the garage and car.

Community health and safety and the economic bottom line, can all be compromised if geology is not considered in development decisions. The Central Antigonish County, Land-use Planning and Climate Change Risk Assessment Pilot Project was initiated by the Geological Services Division of the Nova Scotia Department of Natural Resources in 2008 to help communities identify and avoid geohazards like gypsum karst. A detailed description of the project is found in DeMont (2009). The design and production of a geological map and digital database products, in a format that can be readily used by land-use planners, is the principal objective of the project.

An assessment of existing geological databases and maps in 2008 indicated that the acquisition of new field data was required to complete the Antigonish County project. Surficial geology, coastal zone, and geohazard mapping were identified as areas requiring further studies.

A LiDAR survey flown in December 2008 provided critical new data for the three mapping surveys. This Light Detection And Ranging (LiDAR) survey provides a detailed, bare-earth view of the study area landscape and topography. It uses a series of high intensity laser beams to accurately measure the distance between the aircraft-borne sensor and the ground surface. A summary report on the 2009 surveys and a discussion on the implications for land-use planning in central Antigonish County are provided below.

Coastal Zone Erosion

A preliminary assessment of the coastal zone, including air and ground traverses, was undertaken by Geological Services Division staff in 2008. Coastal processes in the area and measurement of coastal erosion rates at several sites were reported by Utting and Gallacher (2009). The Antigonish Harbour coastline was not mapped in detail because the barrier beaches developed at the harbour mouth shelter it from ocean waves,

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effectively minimizing the rates of coastal erosion. Nonetheless, coastal flooding could be an issue in the harbour. Low-lying areas vulnerable to flooding will be identified in a flood risk model currently being developed by one of the project partners, Atlantic Geomatics Research Group (AGRG).

Data collected in the 2008 and 2009 mapping surveys will be used in conjunction with coastal erosion rates data provided by AGRG to produce a coastal erosion risk map. The erosion rates will be calculated using ortho-rectified historical aerial photographs and the new LiDAR Digital Elevation Model (DEM). A coastal zone GIS database and map will be produced for the Central Antigonish County Project in the fiscal year 2010-2011 using the format developed in the St. Margarets Bay Coastal Zone Mapping Project (Finck, 2008, 2009).

Repeat traverses were made along some of the coastal sections. Physical changes to beaches and headlands were noted on each traverse, but it was difficult to quantify these changes. In the fall of 2009, DeMont assisted staff from AGRG to conduct a ground LiDAR scan of an eroding drumlin face exposed along Dunns Beach. This scan will be repeated in the spring of 2010, and possibly during the winter of 2011, to produce a quantifiable measure of erosion rates for this drumlin. The data will also provide some insight into erosion processes occurring on this face. To allow accurate placement of LiDAR scanning equipment for the follow-up surveys, a survey post was positioned at the top of the drumlin, using AGRG’s Real Time Kinematic GPS equipment.

A January 2009 site visit to assess damage to the coastline after a major storm identified numerous active earth flows on drumlin bluffs (Figs. 1 and 2), delivering sediment to the beach that would be washed away by wave action. Evidence of earth flows were observed during the 2008 summer field work (Utting and Gallagher, 2009), but at that time the sediment was hardened and little movement was evident. After observing the January 2009 conditions of the drumlin faces we suggest that much of the erosion of drumlins occurs during the winter, while the sediment is water saturated.

Saturation of the sediment and active earth flows might occur during storm events at other times of the year so the repeated LiDAR scans of the drumlin face might determine which events whether summer or winter storms have the greater impact on coastal erosion. If most of the erosion occurs because the sediment has become saturated, a possible mitigation technique might be to ensure the coastal area remains vegetated. Further research is required to confirm this hypothesis. During the coastal traverses a wet soil line was often observed near the top of the dry drumlin faces, immediately below the tree-covered surfaces. If the vegetation is working to hold water in the upper section of the drumlin cliff faces it could also be playing a role in the earth flow process. Changes in vegetation cover and rates of erosion might be determined during examination of the historical aerial photography, a continuing component of this study.

The airborne LiDAR survey coverage extends east, beyond the central Antigonish County boundary line so reconnaissance coastal mapping traverses were completed in this extended coverage area. The railway corridor, which follows the coastline east of Pomquet Harbour, sits on eroding drumlins (Fig. 3). In some areas the track is located precariously close to the cliff edge. Further mapping studies are required to assess the degree of risk associated with erosion and collapse of the till banks underlying the rail line because this is an important provincial transportation corridor.

Surficial Geology Mapping

The LiDAR hillshade image is a powerful tool to examine the surficial materials in the area. Exposed bedrock and glacial materials are the ‘living layer’ on which houses, roads and businesses are built, and where farming and agriculture occurs. Karst topography presents a risk of sinkholes (discussed in the geohazards section). Glacial deposits such as drumlins provide a substrate for productive farmland and sediment for beaches, and glacial deltas can be used for aggregate material. An understanding of the glacial history of the area is needed to predict the distribution of glacial material, especially where it is obscured by vegetation or in areas subject to multiple periods of glacial advance and deposition. In the latter case, there could be a layering of glacial deposits, each of which has different physical and chemical properties. As an example, glacial channels

Figure 1. A series of earth flows are seen along the drumlin cliff face at Havre Boucher.

containing deposits of sand and gravel could be buried beneath till from a later glacial advance. The buried channel sands would make excellent aquifers if they were identified by surficial mapping.

The LiDAR hillshade image provides visual insight on the glacial history of the central Antigonish area, with a glacial ice flow direction toward the northeast the most evident. The imagery, in combination with regional stratigraphy and detailed field mapping, supports an interpretation of earth flow taken at a different coastal site than those seen in multiple glacial events. The first glacial event recorded in the area is an ice-flow phase toward the east, as identified by Stea *et al*. (1989) at Ballantynes Cove, based on pebble lithologies in till. This was followed by a northeastward flow into St. Georges Bay (Stea *et al*., 1989). Warming and glacial retreat resulted in the impounding of a lake in the St. Georges Bay area (Stea and Mott, 2005), based on deposits in the Judique (Cape Breton Island) and Lismore areas to the east and west, respectively. This phase was followed by a re-advance during a cooling phase known as the Younger Dryas (Stea and Mott, 2005). This event is likely responsible for the final northeastward surface morphology of the drumlins on the LiDAR imagery. As this ice retreated it was followed by the formation of another glacial lake in the area, based on the same sections at Judique and Lismore, deltaic deposits at approximately 50 m elevation, and some lacustrine and clay deposits in the area (Fig. 4). Following draining of this glacial lake, sea level was well below present (Shaw *et al*., 2002).

A new surficial geology map for the area covered by the LiDAR survey in the central planning zone

Figure 2. Enlarged view of an earth flow taken at Dunns Beach.

Figure 3. The rail line sits on eroding drumlins east of the central Antigonish County study area.

is in progress and will be completed in fiscal year 2010-2011. This will be prepared in combination with existing maps for a full coverage of the Central Antigonish Planning Area.

Geohazard Mapping

Karst terrain developed over gypsum and limestone, slope stability and coastal erosion are the main geohazards identified in the central Antigonish County study area. Locally, there are anomalous concentrations of heavy metals in soils and bedrock. The 2009 field studies focused on the identification and mapping of karst terrain using the LiDAR hillshade image. Three styles of karst terrain were identified in the study area: (1) sinkholes developed over areas underlain by thick beds of flat-lying or shallow-dipping gypsum, (2) sinkholes formed along fault structures and (3) sinkholes formed in thinly bedded, steeply dipping limestone or gypsum.

Type 1 karst (Figs. 5 and 6) is the most common style observed in the Antigonish Basin, particularly along the west side of Antigonish Harbour. Massive beds of Bridgeville Formation gypsum and anhydrite underlie Antigonish Harbour and the surrounding coastline. The massive nature of these beds and the deeply weathered exposures make it difficult to accurately measure bedding dips, but in most areas the beds appear to be flat lying or shallow dipping.

Along the east side of the harbour, and in the Williams Point area, gypsum is exposed along the flanks of northeast-trending basement ridges. The granite ridges are associated with prominent magnetic anomalies seen on the airborne magnetometer maps (Geological Survey of Canada, 1982a, b). A similar, but weaker magnetic anomaly located along the west side of the harbour may also be the site of a buried basement ridge.

Sinkhole development in type 1 areas is extensive and deep. Sinkholes have formed on over 20% of the area (Fig. 7) mapped as Bridgeville Formation by Boehner and Giles (1982). The sinkholes show considerable variability on both width and depth. Accurate measurements were not taken, but depths ranging from 3-15+ m and widths of 5-30+ m were observed in most areas. Locally, within the karst

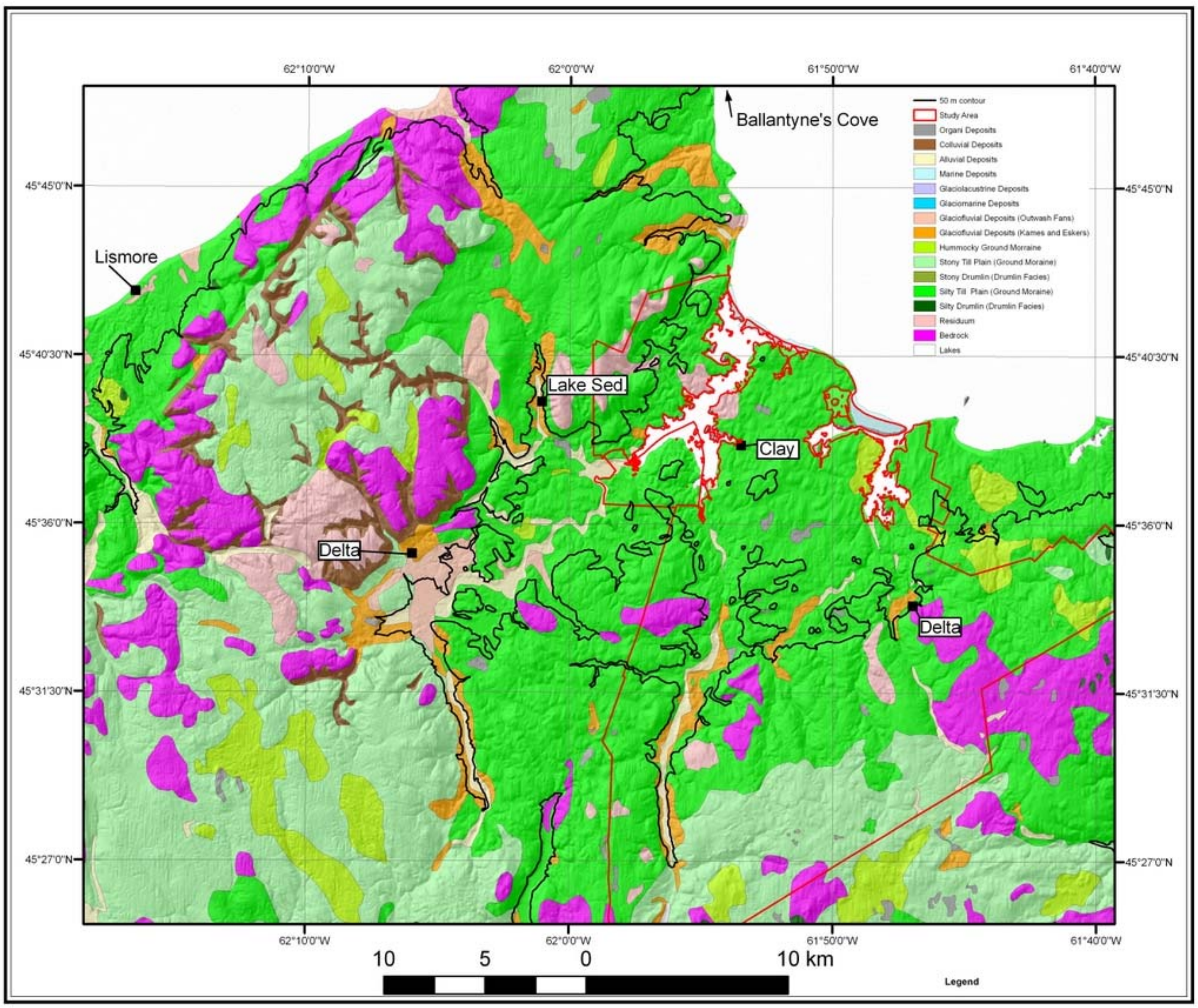

Figure 4. Surficial geology map (after Stea et al., 2006) of the northern portion of central Antigonish County.

terrain, there are pronounced ridges that make natural trails or roadways. These ridges are assumed to be underlain by cap rock that is less soluble than the surrounding gypsum.

Both on the ground and in the LiDAR images, the change from karst to non-karst terrain is often pronounced. On the bedrock geology map (Boehner and Giles, 1982), a large area located along the west side of Antigonish Harbour is mapped as Bridgeville Formation gypsum and anhydrite. As expected, extensive type 1 karst is developed in this area, but there are also large tracts of land underlain by Bridgeville Formation gypsum that exhibit few visible signs of sinkhole development. Most of the areas mapped as Bridgeville Formation and without sinkholes are covered with drumlins. Does this mean that (1) there is no gypsum beneath the drumlins, (2) the low-permeability drumlin material prevents formation of sinkholes, (3) the formation of new sinkholes is imminent, or (4) the thick glacial deposits have infilled pre-existing sinkholes, preventing further sinkhole development? Finding a geological explanation for this is important because the areas showing little to no signs of karst are currently being developed for residential subdivisions.

Two distinct transitions from karst to non-karst terrain are seen on the LiDAR hillshade image along the west side of Antigonish Harbour. In most cases the change occurs at the edge of drumlin hills where it appears that till cover either slowed or prevented sinkhole development. Signs of new sinkholes are visible in the LiDAR image over the till-covered areas. Local landowners also told stories of small holes appearing overnight in their

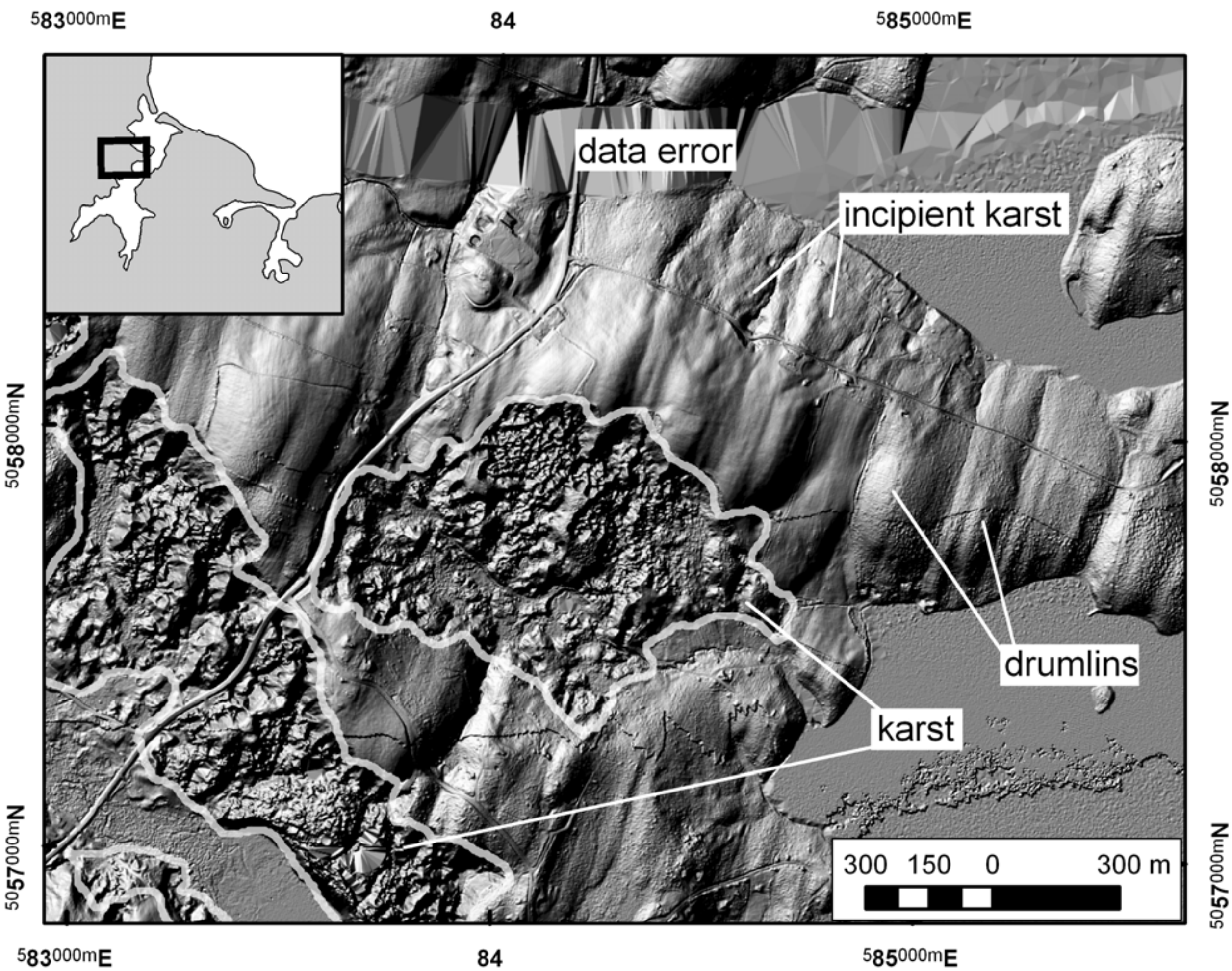

Figure 5. Type 1 karst terrain in Bridgeville Formation gypsum beds.

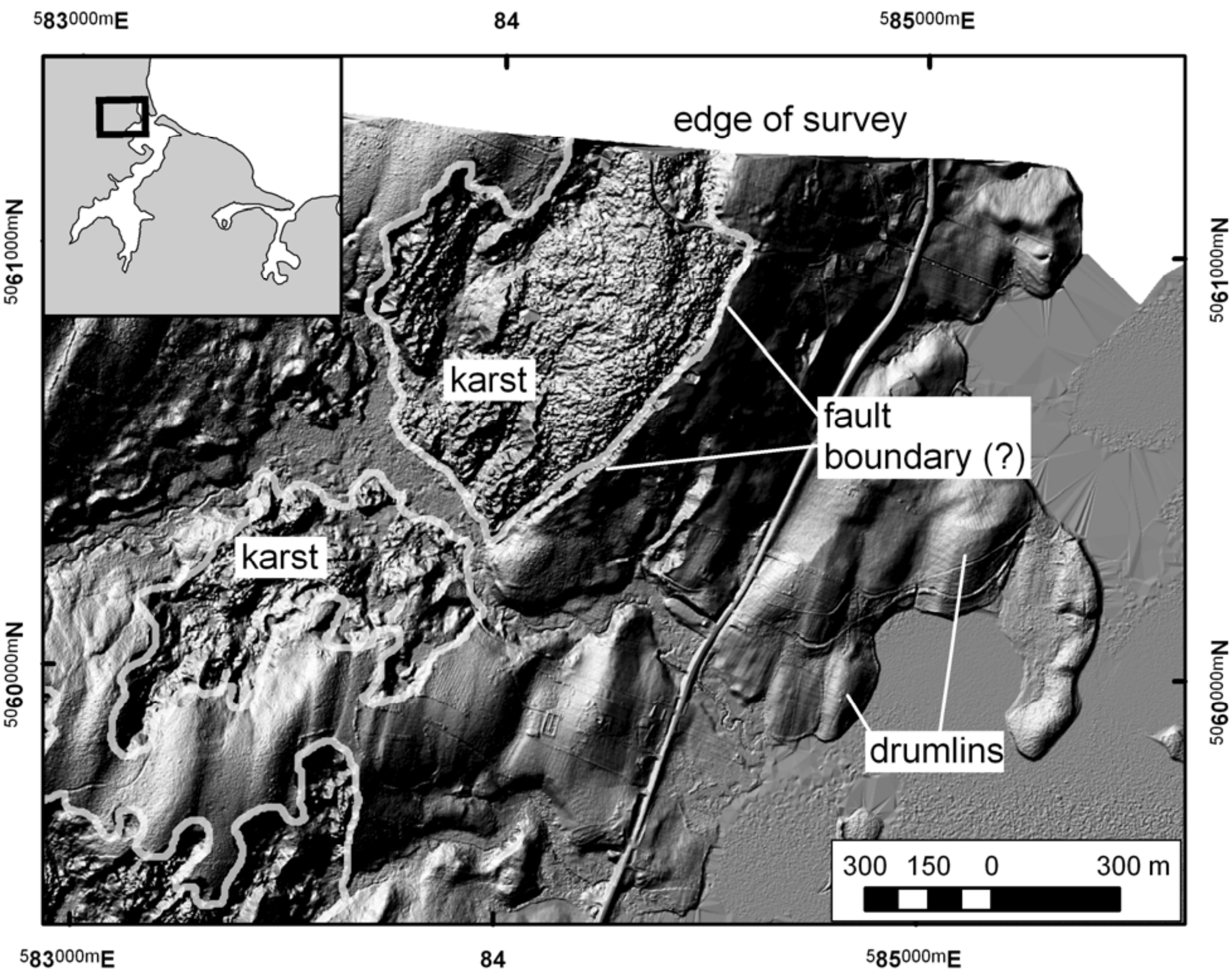

Figure 6. Type 1 karst terrain exposed along the Lanark Fault.

fields, and in one particular case, a woman watched a piece of the farm disappear while she was peering out the kitchen window. One curious observation is an apparent lack of gypsum clasts within the overlying tills, because this raises questions as to the age of the karst. If the sinkholes developed prior to glaciation, gypsum clasts should have been torn off the bedrock surface and incorporated in the till as the glaciers advanced across the study area. On the ground, other evidence was found to suggest sinkhole development is an active process. This includes: (1) shallow subsidence of land surfaces along the edge of fields adjoining the karst terrain, (2) surface cracks in the soil paralleling the field-karst interface, and (3) bent tree stems (pistol butted) on steep slopes along the field-karst interface, indicating slow down-slope soil creep.

The second transition type is located west of Harbour Centre where a large area of deep karst is exposed a short distance northeast of a groomed hiking trail (Trail B of the Fairmont Ridge Trails). At this site a northeast-trending lineament marks the edge of the type 1 karst, and the approximate mapped position (Fig. 6) of the Lanark Fault (Boehner and Giles, 1982). The sharp nature of the line marking the gypsum contact suggests the area east of the line is underlain by a non-soluble rock type. An airborne magnetic anomaly described above is located in the area covering the northeastern half of the lineament. If this anomaly is related to a buried basement ridge, like that seen along the east side of Antigonish Harbour, Horton Group siliclastic rocks or Gays River-Macumber Formation limestone may occur in the near surface beneath a cover of glacial till. This change in rock

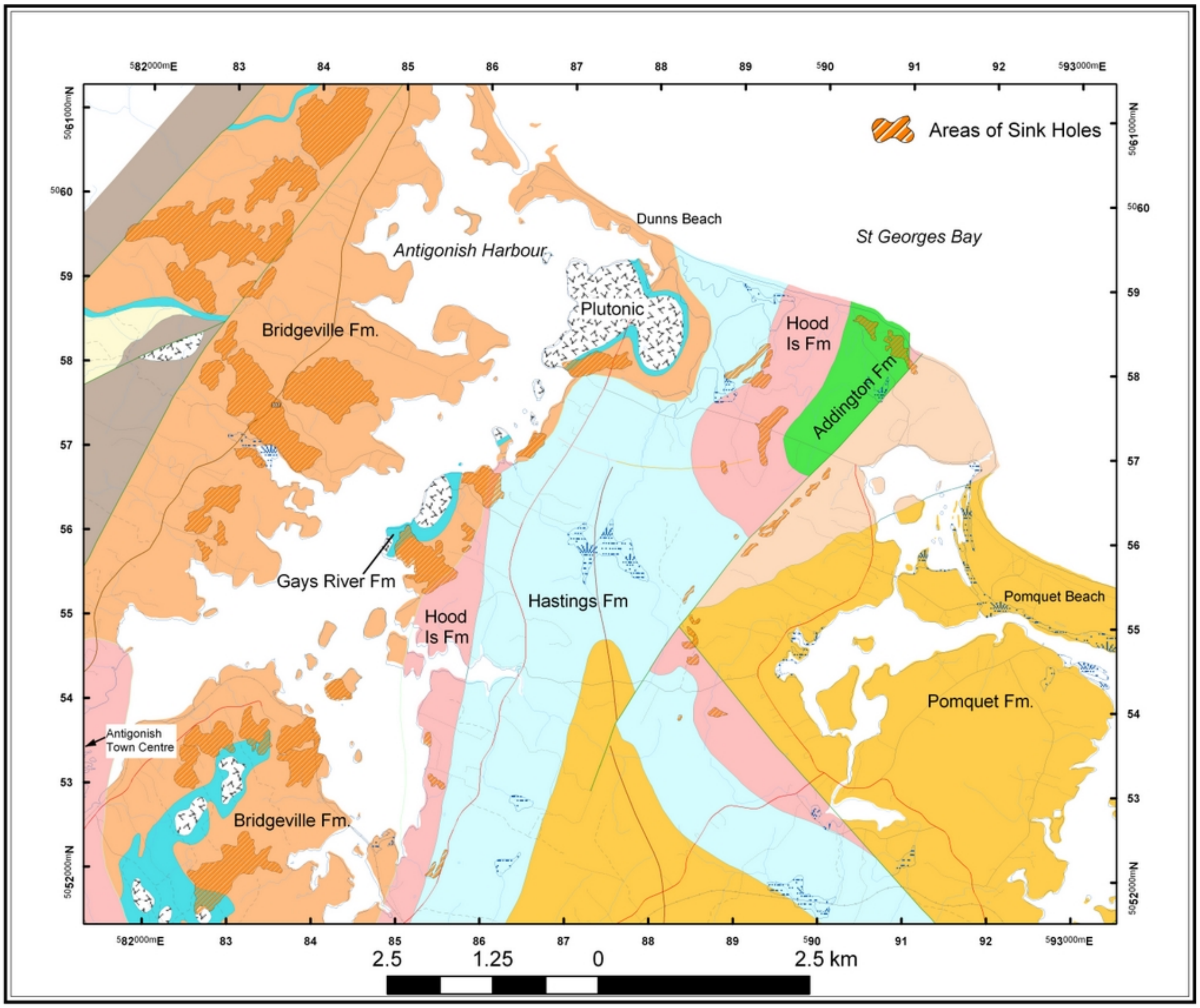

Figure 7. Bedrock geology map (after Boehner and Giles, 1982) showing the Bridgeville Formation and the areas of karst.

type could explain the rapid change from karst to non-karst terrains. The other possibility is that gypsum was juxtaposed against non-soluble rocks as a result of movement along the Lanark Fault.

An example of type 2 karst is found on the LiDAR hillshade image. It is located a short distance west of Pomquet Harbour, along the Monks Head Fault (Fig. 8). This site was not checked in the field in 2009, but on the LiDAR image the sinkholes appear shallow. The karst could be related to movement along the Lanark Fault that exposed buried limestone or gypsum beds, or alternatively, it could be type 3 karst associated with thin, steeply dipping beds of limestone or gypsum. This site is on the list to be field checked in 2010.

An example of type 3 karst (Fig. 9) is found to the east and west of the road leading to the beach at Captains Pond. The sinkholes are easily overlooked on the ground, but they show up as prominent features on the LiDAR hillshade image. The sinkholes form shallow linear swamps or circular depressions flanking steep or subtle bedrock ridges. The shallow depressions and subtle ridges are difficult to detect using aerial photographs or field surveys but are readily observable on the LiDAR hillshade image. Two series of diamond-drill holes

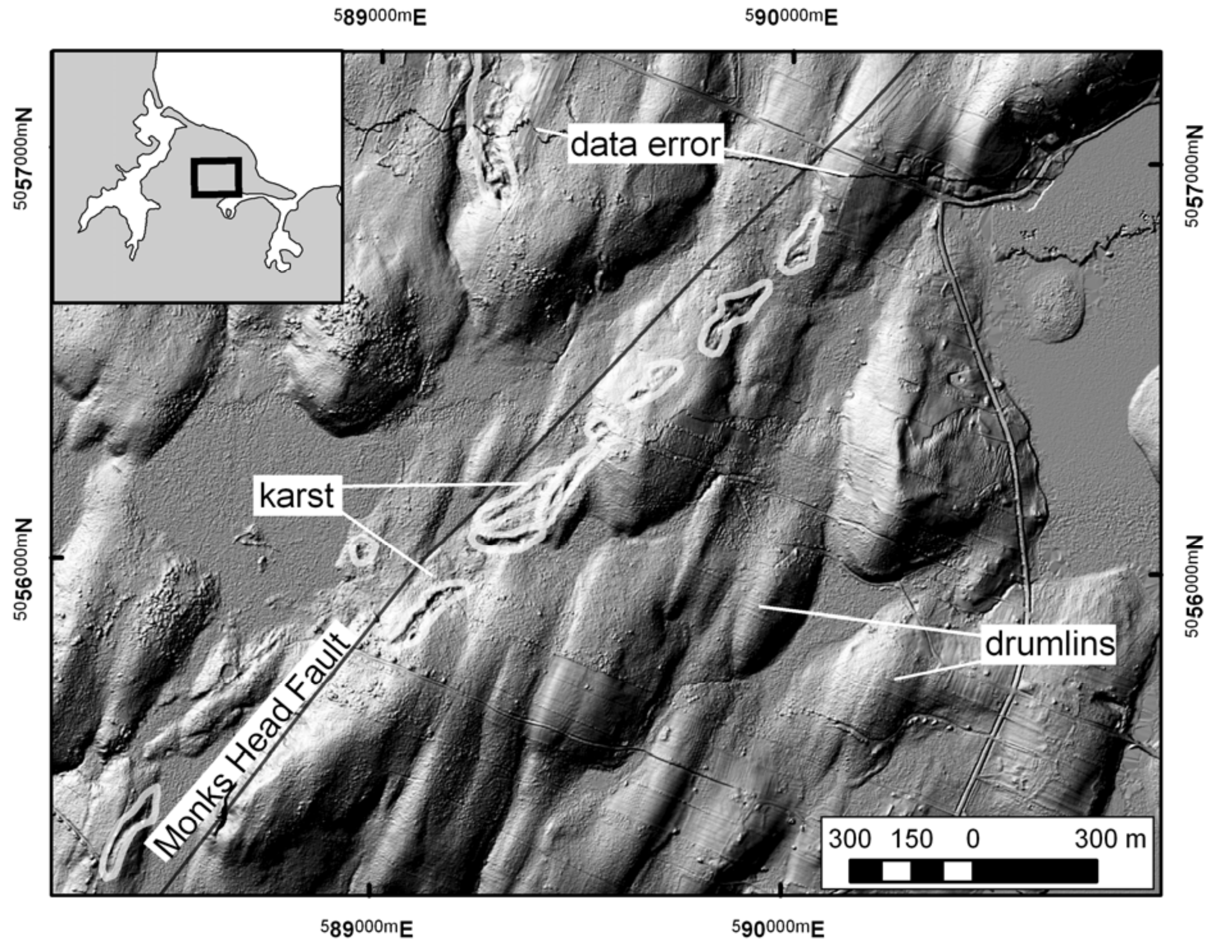

Figure 8. Shallow sinkholes seen along the trace of the Monks Head Fault.

were drilled in this area, one to test the limestone exposed in the bedrock ridges (Murray, 1975) and the other to explore for base metals in the dolomitic limestone units (Johnston, 1974). The drillholes intersected a stacked sequence of steeply dipping, interbedded limestone, dolomitic limestone, shale or mudstone, sandstone and gypsum. Subsurface voids or cavities were encountered in the drillholes in gypsum, limestone and calcareous mudstone beds.

Challenges for Land-use Policy

The central Antigonish County mapping surveys identified areas of considerable risk for future development. The challenge now is to turn this knowledge into a product that land-use planners can use to guide future development in the study area. Restrictive covenants should be used in the development permitting process in areas of karst terrain and within the coastal zone. The mapping results also suggest that single blanket policies will not work. For example, in areas of types 2 and 3 karst it should be relatively easy to map the risk zone and then apply fixed development setbacks. In the case of type 1 karst, however, there is clear evidence that sinkholes are expanding and new ones are forming. If planners use the same fixed setback guidelines developed for types 2 and 3 karst, developments will still be at risk. In type 1 areas, modifications to drainage and excavations into overlying till might be potential triggers for sinkhole development. In this case an on-site geotechnical assessment might be suitable prior to these land-use changes.

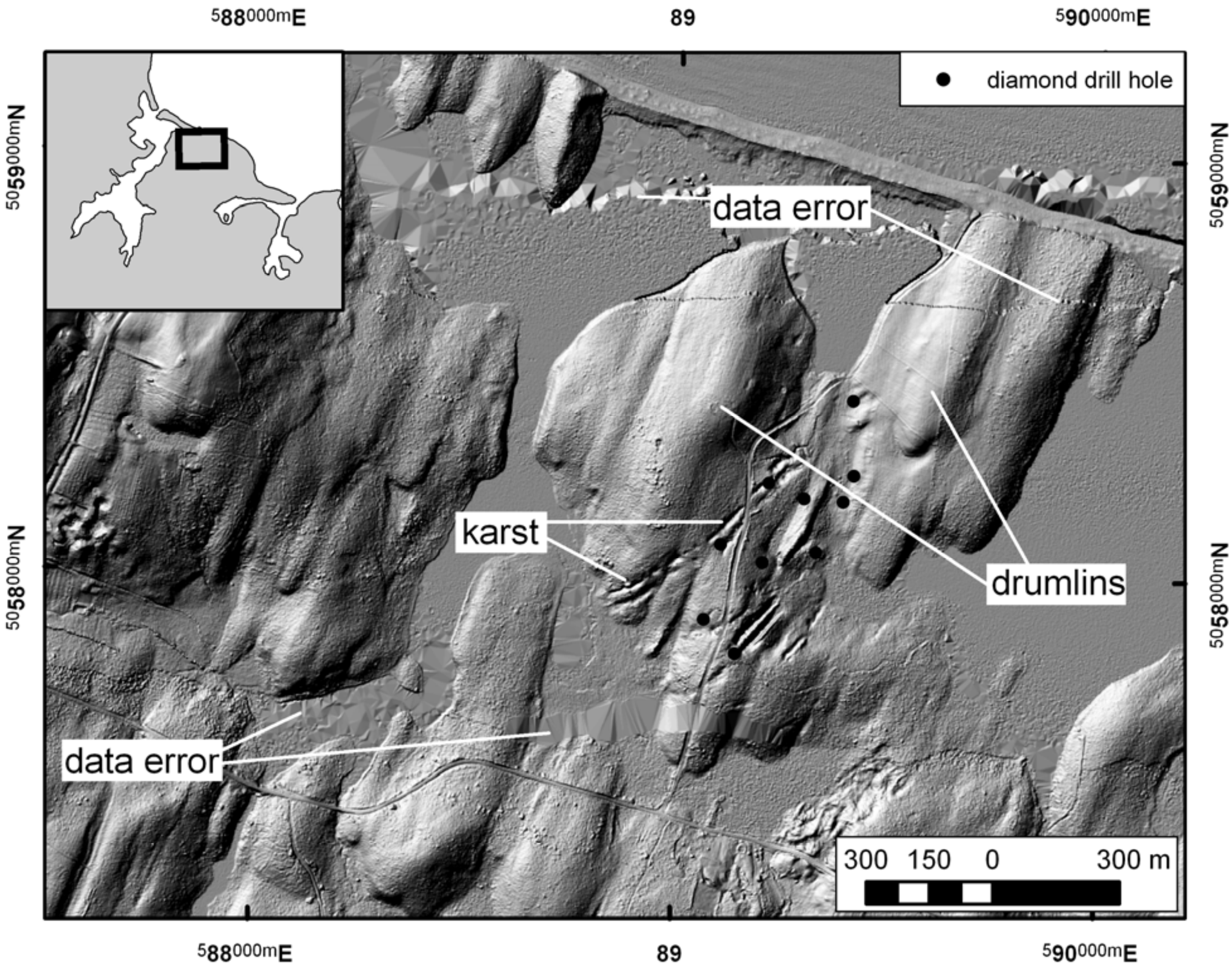

Figure 9. Sinkholes developed in steeply dipping beds of limestone and gypsum.

Mapping the Antigonish area will likely be the easy part of the project. Producing map and database products in a format that land-use planners will use is the big challenge, but it will be well worth the effort. It is important for geology to find its way into the land-use planning process to ensure we have safe, healthy and prosperous communities in Nova Scotia.

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