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Open File Report 5751

The Precambrian–Paleozoic Unconformity and Related Mineralization in Southeastern Ontario

1991

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ONTARIO GEOLOGICAL SURVEY

Open File Report 5751

The Precambrian-Paleozoic Unconformity and Related Mineralization in Southeastern Ontario

by

G. Di Prisco and J.S. Springer

1991

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V.G. Milne

V.G. Milne, Director
Ontario Geological Survey

FOREWORD

For a period of roughly 400 Ma, between the Late Proterozoic and the Ordovician, the Precambrian bedrock of southeastern Ontario was subjected to weathering in a tropical environment. This weathering event formed a variety of mineral deposits which were preserved by burial by carbonate sediments in the Middle Ordovician.

Although the existence of these deposits has been long known, they had not been studied in detail. This report describes in detail the unconformity surface and related mineral deposits, and develops an exploration model for these unconformity-related mineral deposits.

This study will be of interest to geologists interested in unconformity-related mineral deposits, prospectors in southeastern Ontario, and researchers studying the Precambrian-Paleozoic unconformity in Ontario. The results of this study will also be of relevance to petroleum geologists drilling for oil in the subsurface of southwestern Ontario.

This program was funded under the 1985 Canada-Ontario Mineral Development Agreement (COMDA), a subsiduary agreement to the Economic and REgional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

V.G. Milne
Director
Ontario Geological Survey

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ABSTRACT

For a period of roughly 400 Ma, between the Late Proterozoic and the Middle Ordovician, the Precambrian bedrock of southeastern Ontario was subjected to weathering in a tropical environment. Karst surfaces, paleosols, laterites, and supergene enrichment of existing mineral deposits developed this bedrock surface, which was subsequently covered by Middle Ordovician clastic and carbonate sediments. This study reports on a field and literature study of the Precambrian-Paleozoic unconformity in southeastern Ontario and the mineralization found along this unconformity.

Two types of mineralization are present related to the unconformity. The first consists of mineral deposits directly related to weathering, and includes hematite deposits formed by oxidation of Precambrian iron skarn deposits, gold concentration above auriferous sulphide veins, and manganese and uranium oxides. Most mineralization found near the unconformity is of this type. The second type of mineralization consists of mineral deposits indirectly related to the unconformity, such as the post-Ordovician carbonate-barite-galena veins. In this case, the unconformity has served to focus post-Precambrian fluid flow and ore deposition.

The best prospecting targets related to the unconformity are paleodepressions with regolithic concentrations (commonly found beneath thick accumulations of Paleozoic strata) and karst systems in dolomitic marbles found adjacent to Precambrian intrusions, particularly the deeper parts of such karst systems.

The Precambrian-Paleozoic unconformity in southeastern Ontario is similar to other unconformities found elsewhere in the world, and metallogenic models developed elsewhere are applicable to Precambrian-Paleozoic unconformity in southeastern Ontario. In addition to discussing the mineral potential of the unconformity in Ontario, this report also describes in detail numerous sites where the Precambrian weathering surface is exposed in southeastern Ontario.

THE PRECAMBRIAN - PALEOZOIC UNCONFORMITY AND RELATED MINERALIZATION IN SOUTHEASTERN ONTARIO

by G. Di Prisco[1] and J.S. Springer[1]

[1]Geologists, Ontario Geological Survey, Precambrian Geology Section

INTRODUCTION

History of the project

A major sedimentary gap in the geological record exists between the Late Proterozoic and the Early Paleozoic in southeastern Ontario. This Precambrian-Paleozoic unconformity in southeastern Ontario can be correlated with other unconformities of the same age in Canada, the United States and parts of Europe, where important Middle Ordovician marine transgressions cover the erosion surface and where a variety of mineral deposits may occur (Cumming 1968, Harris 1971, Maher 1971, Zuffardi 1976, James et al. 1988).

During the course of regional mapping in southeastern Ontario, Springer (1983), drew attention to the presence of an erosion surface beneath the unmetamorphosed Paleozoic rocks which likely represented an exhumed Precambrian paleosurface. As a consequence, many previously recorded mineral deposits (MacFarlane 1866, Vennor 1870, Blue 1894, Slaght 1898, Guillet 1962, MacKinnon et al. 1985) at this surface, could be due to Precambrian supergene enrichment. In addition, Sangster and Bourne (1982), and Carter (1984), noted a secondary association between some types of ore deposits and pre-Ordovician events along the unconformity.

In spite of the presence of known mineral deposits at the unconformity surface, the importance of an exhumed pre-Ordovician paleosurface as a focus for mineral exploration was unrecognized and with it, the understanding that a model of unconformity-related mineralization can not only predict the type of commodities to be expected, and the location of such commodities, but also the nature and depth of mineralization, thus offering new possibilities for exploration.

In order to fully explore the mineral potential of the Precambrian-Paleozoic unconformity in southeastern Ontario, in 1983, the authors proposed two models of mineralization environments related to the unconformity which could be field tested.

Critical Readers: R.M. Easton and B.O. Dressler.

Report approved for publication by B.O. Dressler, Acting Section Chief, Precambrian Geology Section, Ontario Geological Survey, January 9, 1990.

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One model predicted the presence of a suite of minerals situated at the paleosurface and related to weathering processes. The other model predicted the presence of ore bodies, in both cover and basement rocks, controlled by the primary and secondary permeability of the Precambrian and Paleozoic rocks, and related to flooding of open cavities by warm brines.

In the same year a proposal to field test these models was presented, and later accepted, for funding as a three-year project as part of the Canada-Ontario Mineral Development Agreement (COMDA). This is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

Objectives and Methodology of Work

The objectives of this three-year project were, first, to delineate the distribution of the Precambrian-Paleozoic unconformity in southeastern Ontario, and second, to identify and examine mineral occurrences associated with the unconformity. A third objective was to test the models of mineralization proposed by the authors, and to assess the role of the unconformity in mineralization processes, thereby predicting the location of other occurrences of mineralization.

Most of the study was carried out along the south flank of the Algonquin Dome, in a region extending from Kaladar-Tweed in the east, to Minden-Norland in the west (Figure 1). A few localities were also investigated south and north of the Frontenac Axis, and northeast of the Algonquin Dome along the Ottawa River Valley.

Field work consisted of locating and documenting outcrops showing the unconformity, particularly where mineralization was present. Road cuts, quarries and drill cores were the principal sources of information for this survey. In addition, mineralogical and geochemical analyses were carried out to assess the mineralogical and geochemical modifications of the rocks at the unconformity. Field work was conducted during the summers of 1986, 1987, and 1988. Preliminary reports on this project were made in 1985, 1986, 1987, and 1988 (Springer 1985, Di Prisco 1986, 1987, Di Prisco and Springer 1988).

Geological Setting of the Study Area

Introduction

The study area is underlain mainly by Middle to Late Proterozoic rocks of the Grenville Province, which form a major orogenic belt on the southeastern margin of the Canadian Shield.

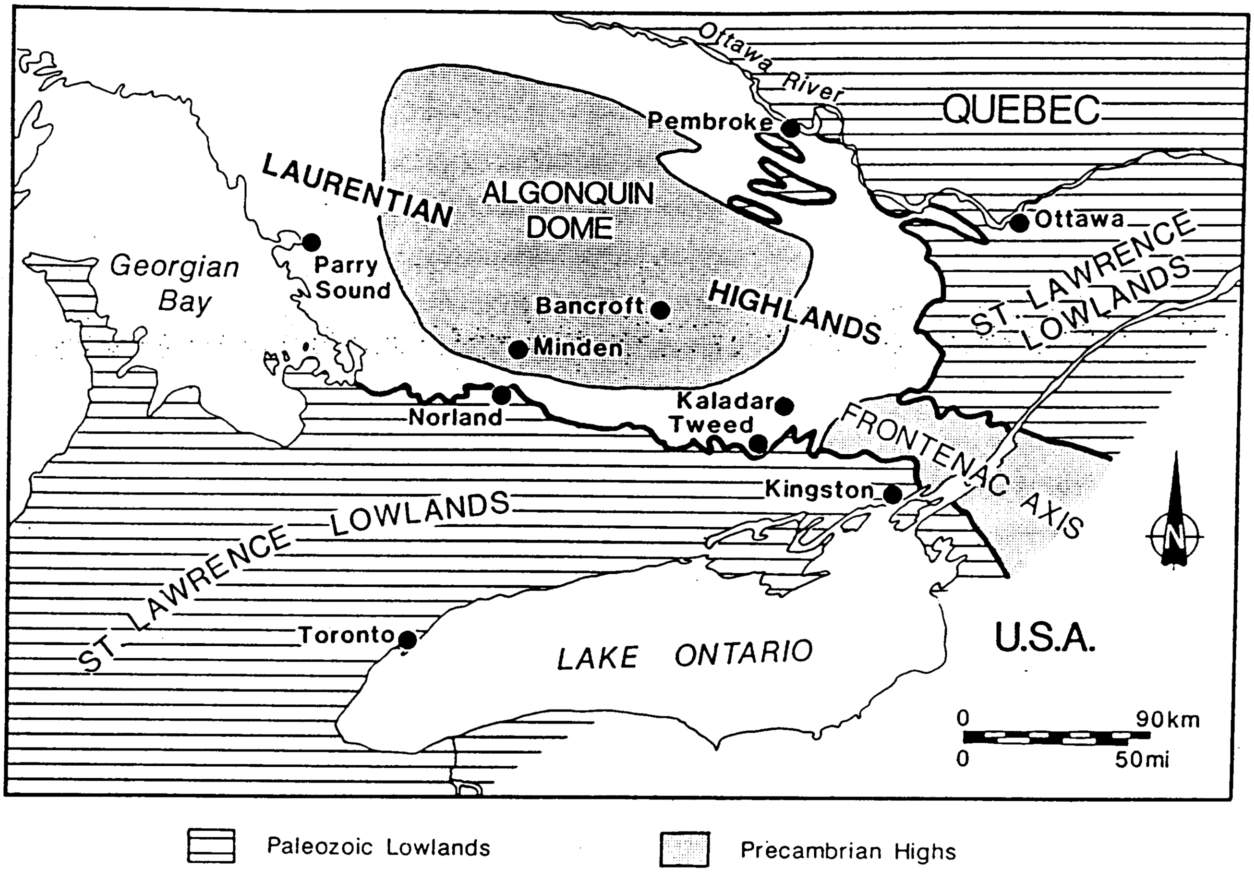


Figure 1: Physiographic and geological elements of southeastern Ontario. The study area was located between Norland-Minden in the west and Kaladar-Tweed in the east.

In Ontario, the northwestern Grenville Province is separated from the relatively low metamorphic grade rocks of the Superior and Southern Provinces by the Grenville Front, while to the south and southeast, the Precambrian basement is overlain by Paleozoic sedimentary rocks of the St. Lawrence Lowland (Figure 2).

Precambrian

The Grenville Province is subdivided into several major lithotectonic domains (Wynne-Edwards 1972) (Figure 2). The study area lies in the Central Metasedimentary Belt (CMB) which is characterized by a major accumulation of Middle Proterozoic supracrustal rocks (Figure 3).

The lithology and stratigraphy of the Precambrian rocks of the CMB are among the best known of the Grenville Province. Moore (1982) subdivided the CMB into a number of allochthonous lithotectonic supracrustal sequences or terranes (Figure 4). The Madoc-Marmora area, where most of this study was conducted, lies within the Elzevir Terrane. Lithostratigraphic subdivision of these rocks have been proposed by several authors. Table 1 from Carter (1984) summarizes these subdivisions in the Elzevir Terrane. The Middle Proterozoic basement on which the unconformity is developed includes volcanic, volcaniclastic, and intercalated carbonate and siliciclastic sedimentary rocks of the Grenville Supergroup (Table 1) (Lumbers 1967) all intruded by several plutonic suites. The Flinton Group, overlying the Grenville Supergroup (Table 1) (Moore and Thompson 1972, 1980) consists of carbonate and clastic sedimentary rocks.

The study area is underlain mainly by thick and extensive carbonate metasediments which were metamorphosed from lower greenschist to lower amphibolite facies. The low degree of metamorphism in the carbonate rocks likely contributed to increased development of weathering features at the unconformity surface.

Table 2 summarizes the geologic events from the Middle Proterozoic to the Early Paleozoic in the Central Metasedimentary Belt. The latest events affecting the Precambrian rocks ended around 1000 million years ago, with Paleozoic sedimentation occurring on the Precambrian basement during the Middle Ordovician at around 465 million years ago. Thus, a major gap in the earth's stratigraphic history occurred in the study area, during which geological events, other than marine sedimentation, occurred on a subaerial Precambrian surface (Table 2).

Paleozoic

The Paleozoic rocks unconformably overlie the Precambrian basement south and northeast of the CMB (Figure 2, 3). In the study area, abundant outliers of Paleozoic rock crop out in a zone up to 15 km wide bordering the main Precambrian-Paleozoic boundary, and vary in size from a few metres to several kilometres wide. The unconformity itself is difficult to map precisely, mainly because widespread Quaternary overburden generally obscures the Precambrian-Paleozoic contact.

Nomenclature used for the description of the Paleozoic rocks largely follows the classification of Liberty (1963, 1969) summarized in Table 3. The Paleozoic lithostratigraphic units encountered in the region are, in ascending order, the Shadow Lake, Gull River and Bobcaygeon Formations, of the Basal and Simcoe Groups.

The Basal Group in the study area is represented by the Shadow Lake Formation. This formation consists of red conglomerate, red and green sandstone and arkose, siltstone and shale, with minor interbedded limestone in the upper part. The Simcoe Group consists mostly of limestone, dolomitic limestone, and minor dolomite of the Gull River and Bobcaygeon Formations.

According to Liberty (1969), the Simcoe Group represents a "carbonate sequence lying above the basal clastic sediments of the Shadow Lake Formation", and

Carson (1981a,b) notes that the transition between the Shadow Lake and the Gull River Formations (between the Basal and Simcoe Groups) marks "the last appearance of clastic sedimentary units and the beginning of virtually continuous carbonate units". However, field work by the authors has located several outcrops of clastic Paleozoic sedimentary rocks, other than the Shadow Lake Formation, resting unconformably on the Precambrian basement (Table 4). These units are composed mostly of red and green conglomerate, immature coarse sandstone, and clastic limestone, all rich in quartz fragments varying in size from 1-2 cm to 15 cm. The thickness of these units is variable but can be as thick as 2.3 m. The units are overlain with apparent conformity by carbonate sediments dated on fossil evidence as being part of the Bobcaygeon Formation. Nonetheless, these units which represent a basal clastic facies, possibly of Precambrian age, have commonly been assigned to the Shadow Lake Formation. These clastic units occur on the flanks or the top of Precambrian paleohighs and laterally the clastics facies become the typical carbonate sediments of the Gull River or Bobcaygeon Formations.

Thus, it appears that there is widespread development of a diachronous clastic unit locally associated with the Precambrian paleosurface. This unit varies considerably in composition and thickness, reflecting the basement rocks beneath. Because correlation is largely impossible, it is convenient to recognize the lithological distinctiveness of the unit and to avoid stratigraphic classification. Thus, in this report, only clearly identified Shadow Lake Formation rocks will be referred to as such. Otherwise the authors will use the expression "basal clastic unit" to describe the first unmetamorphosed clastic sediments resting unconformably above the Precambrian rocks.

Sources of Geological Information

The principal geological maps used during this study are summarized in Table 5. Only part of the area is covered by detailed mapping.

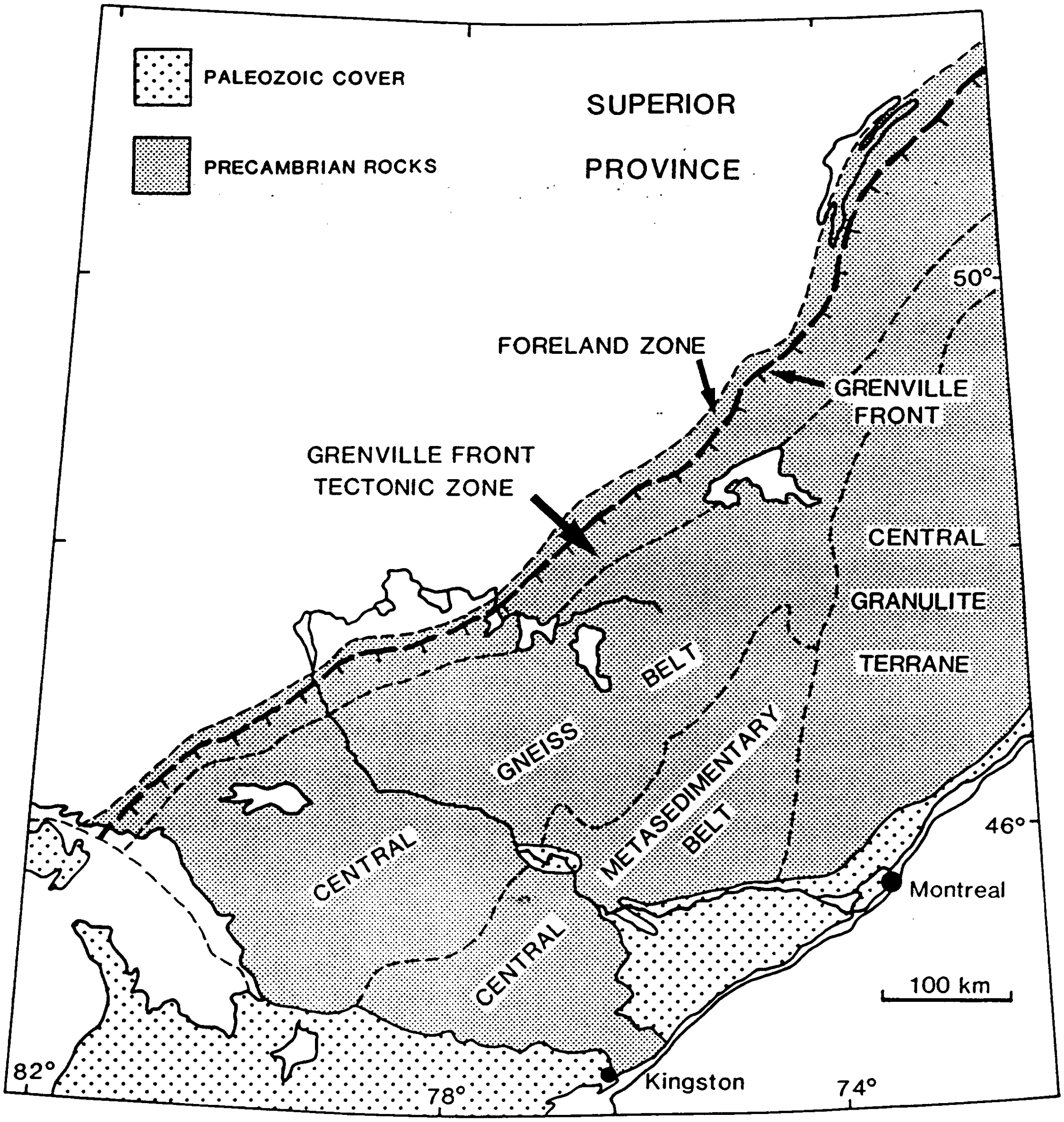


Figure 2: Structural subdivisions of the western Grenville Province, Ontario and Quebec.

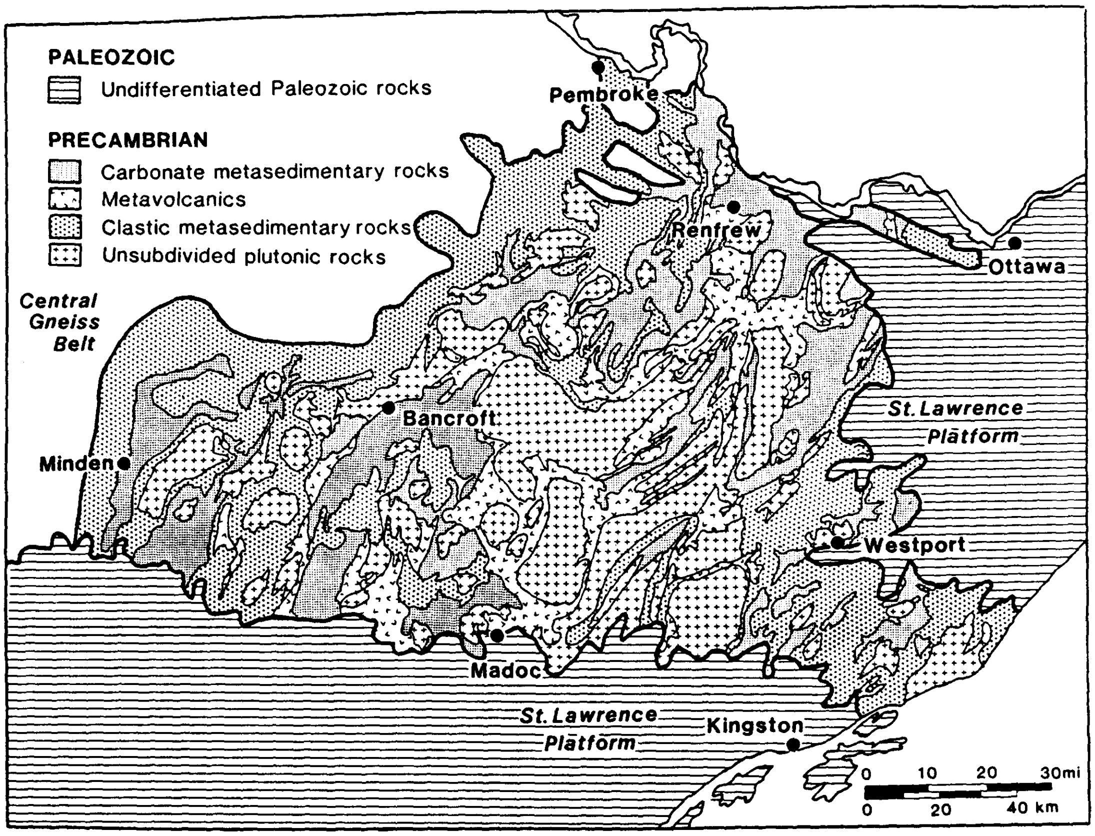


Figure 3: General geology of the Central Metasedimentary Belt, Grenville Province, southeastern Ontario. Adapted from Carter (1984)

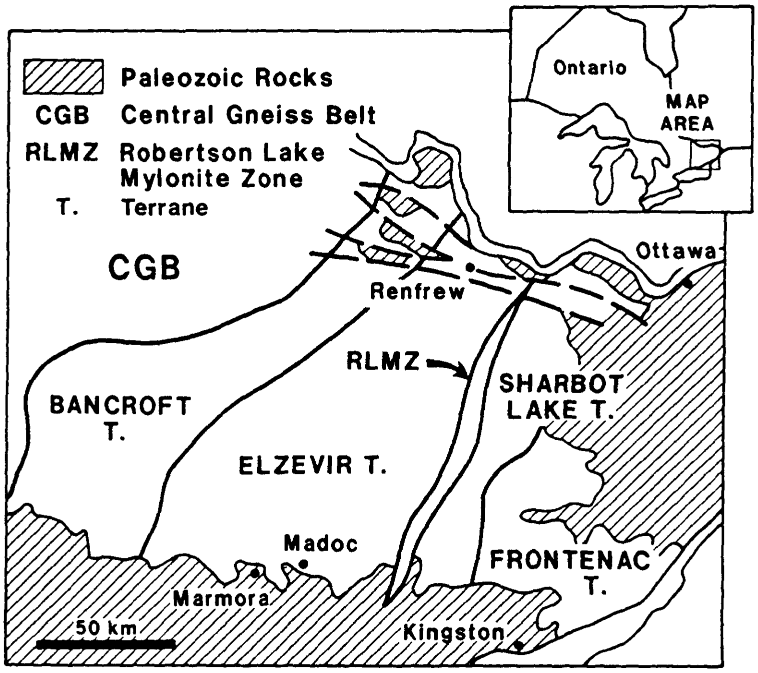
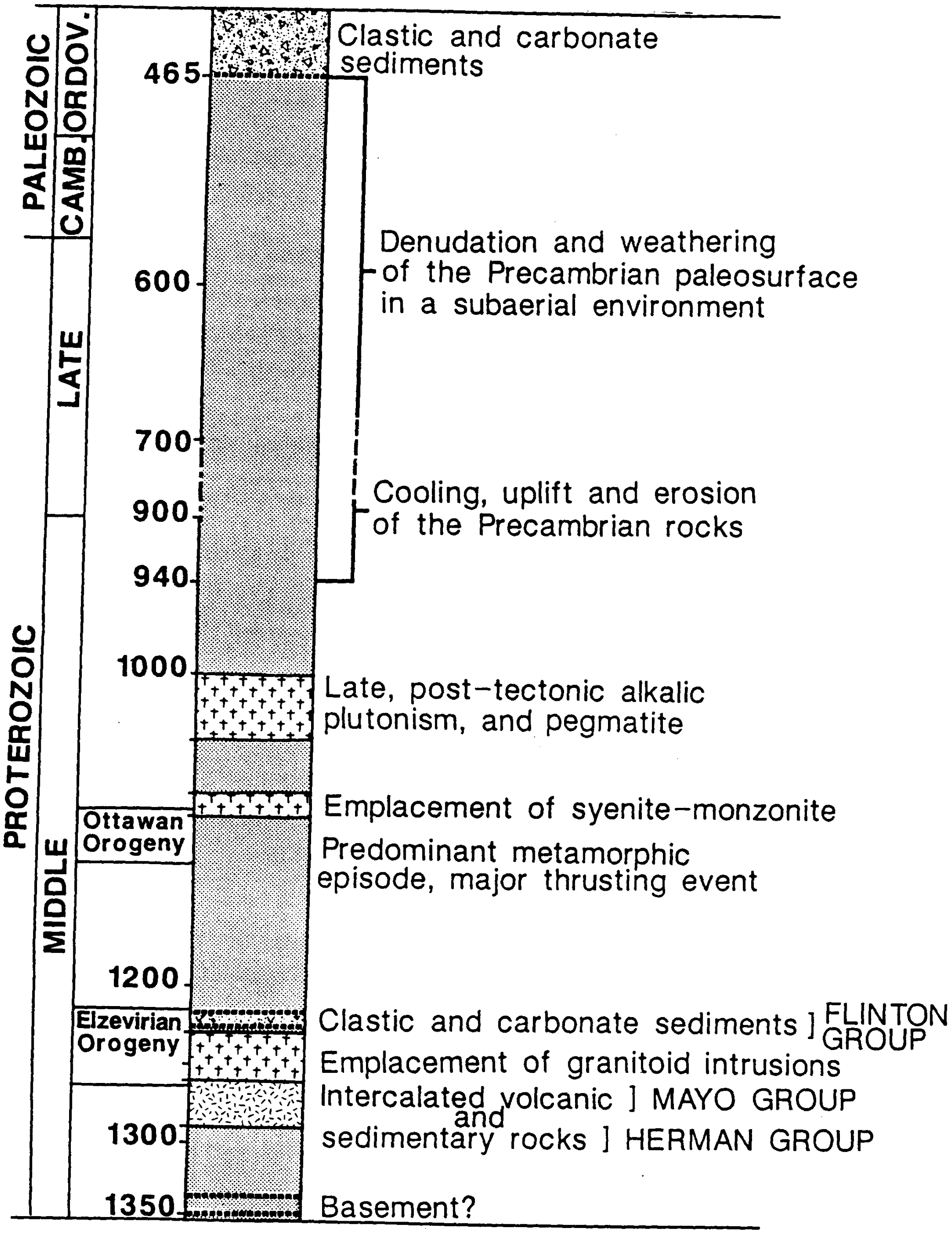


Figure 4: Structural subdivisions of the Central Metasedimentary Belt, Grenville Province, southeastern Ontario. Adapted from Easton (1988)

Table 1: Table of the Precambrian formations exposed in southeastern Ontario (Hermon and Mayo Groups after Lumbers 1967, Flinton Group after Moore and Thompson 1972 1980); adapted from Carter 1984

Supergroup	Group	Formation	Description
Grenville	Flinton	Stewart	marble, graphitic marble
		Madoc	pelite
		Fernleigh	thin-bedded black shale and limestone, pyritic in part dolostone, limestone, dolostone
		Myer Cave	conglomerate, black pyritic shale
		Lessard	calcareous and non-calcareous feldspathic sandstone basal, hematitic quartzite (locally
		Bishop Corners	cross-bedded) quartz-pebble conglomerate and shale
		UNCONFORMITY	
	Mayo	Lasswade	marble, minor calcareous metasandstone and metasiltstone, rare recrystallized chert
		Apsley	poorly sorted feldspathic metasandstone with upper and lower members of calcarous metasandstone and metasiltstone
		Dungannon	80% marble; remainder mainly calcareous metasandstone and metasiltstone, poorly sorted feldspathic metasandstone, and rare recrystallized chert; mafic metavolcanic flows and iron formation rare near base of formation overlying Tudor metavolcanics
	Hermon	Burnt Lake	mainly rhyolitic, trachytic, dacitic, and andesitic metavolcanics with minor metabasalt flows; lensoid marble units and sandy siliceous metasedimentary rocks
		Turriff	75% pillowed basaltic and andesitic metavolcanic flows; 20-25% dacitic and felsic flows and pyroclastic rocks, minor iron formation
		Vansickle	mainly poorly sorted feldspathic metasandstone, locally with abundant marble, felsic and mafic metavolcanics, metaconglomerate, and well sorted quartz-rich metasandstone; arkosic metasedimentary rocks commonly associated with felsic metavolcanics
		Oak Lake	mainly metamorphosed felsic pyroclastic rocks and arkose with some mafic and felsic metavolcanic flows; rare marble and metaconglomerate in upper part of formation
		Tudor	mainly metamorphosed pillowed basaltic and andesitic flows

Table 2: Major geologic events in the Elzevir-Bancroft Terranes.



AGE (Ma)	SYSTEM	GROUP	FORMATION	MEMBER	LITHOLOGY
458	MIDDLE ORDOVICIAN	SIMCOE	*LINDSAY		
			*VERULAM		
			BOBCAYGEON	Upper	Crystalline Limestone Calcarenite Limestone Sublithographic Limestone
				Middle	Sublithographic Limestone
				Lower	Argillaceous Limestone Calcarenite Limestone
			GULL RIVER	Upper	Limestone Lithographic Limestone
				Middle	Laminated Limestone Lithographic Limestone
				Lower	Dolomitic Limestone Lithographic Limestone Limestone and Dolomite
		BASAL	SHADOW LAKE		Red and Green Conglomerate Sandstone, Arkose and Shale
478					

* Formations not observed in the study area

TABLE 3: Lithostratigraphic classification of the Paleozoic rocks in southeastern Ontario. Adapted from Liberty 1963, 1969.

LOCALITY NAME	COUNTY-TOWNSHIP	LOCATION - UTM	BASAL PALEOZOIC UNIT (Thickness)	PRECAMBRIAN BASEMENT
Tweed West	Hastings-Hungerford	18T-E313400 N4927550	Coarse immature sandstone, clastic limestone (about 1m)	Granite
Madoc West (Hwy.7)	Hastings-Madoc	18T-E299100 N4930600	Conglomerate immature sandstone, clastic limestone (about 2.3m)	Metavolcanic
Marmora North (Hastings Cty.R.3)	Hastings-Marmora	18T-E286000 N4930200	Coarse immature sandstone clastic limestone (about 1m)	Carbonate metasediment
Allan Mills	Hastings-Seymour	18T-E282900 N4920380	Clastic limestone (quartz and Precambrian clasts)	Metavolcanic

TABLE 4: Location of some Paleozoic basal units other than the Shadow Lake Formation

Table 5: Sources of Geological Information

Map Name	No. Reference	Year	Author(s)	Map Type
Madoc and part of Huntingdon Twp.	OGS Map 2154	1968	Hewitt, D.F.	Detailed 1:31 680, GR 73
Marmora Township North Part	OGS Map P.2612	1983a	Bartlett, J.R. and Moore, J.M.	Detailed Precambrian, 1:15 840
Marmora Township South Part	OGS Map P.2613	1983b	Bartlett, J.R. and Moore, J.M.	Detailed Precambrian, 1:15 840
Howland Area	OGS Map P.2699	1984	Easton, R.M. and Bartlett, J.R.	"
Madoc Area	OGS Map P.2053	1964b	Hewitt, D.F.	Compilation, 1:126 720
Haliburton-Bancroft Area	OGS Map 1957b	1957	Hewitt, D.F. and Satterly, J.	Compilation, 1:126 720
Kaladar-Tweed Area	OGS Map P.2411	1981a	Carson, D.M. Paleozoic, 1:50 000	Compilation
Burleigh Falls - Peterborough Area	OGS Map P.2337	1980a	"	"
Bannockburn-Campbellford Area	OGS Map P.2374	1980b	"	"

EASTERN NORTHERN AMERICA IN THE LATE PROTEROZOIC-EARLY PALEOZOIC

Paleogeographic Setting

Paleogeographic reconstructions of the position of continents (Scotese et al. 1979; Irving 1979) suggest that by the Late Cambrian, the continents were located mainly along or near the equator. They were relatively dispersed and separated by small seas (Scotese et al. 1979). Large oceans capped the polar regions and shallow epeiric seas were common. The proto-Northern American continent, Laurentia, spread 10° north of the equator and 25° south of it. Land area on the eastern shores, particularly between latitudes 20-35°, was traversed by vigorous storm systems. The climate was thus tropical and humid (Marsaglia and Klein 1983).

The broad tectonic context of North America between 600 and 400 Ma is apparent from reconstructions of cratonic North America and the developing Appalachian orogen which bordered it (Williams 1984, Sanford et al. 1984). The Canadian Shield was a tectonically positive area from the Late Proterozoic to the Cretaceous. During the Late Proterozoic, ridges of positive movement radiating across the Canadian Shield had begun to control sedimentary patterns and rates of deposition (Figure 5). On the eastern margin, the development of the Appalachian orogen was marked by the opening and closing of the Iapetus ocean. Crustal collision, related to the Appalachians resulted in the accretion of overthrust lithotectonic terranes, and was reflected by changes of sea level which caused intermittent flooding of the craton margins (James et al. 1988).

In eastern Ontario, the Frontenac Arch, a dominant physiographic feature (Figure 1, 5) was established by the Late Proterozoic and continued to be the most active of the ridges of positive movment that radiated across the Shield area (Sanford et al. 1984). Consequently, in eastern Ontario, the Late Proterozoic-Early Paleozoic interval is largely a period of erosion, and thus, there are few rocks that lie stratigraphically between the metamorphosed basement and the first carbonates of the Middle Ordovician, although elsewhere in Europe and North America the same interval is represented by thick terrestrial or marine deposits.

In eastern Ontario, the Potsdam sandstone of probable Cambrian age reflects several terrestrial environments, namely estuarine, aeolian, braided river and wadi flash floods (R.G. Walker, geologist, McMaster University, personal communication 1988) and developed on a continental area rimmed and later partly flooded by shallow seas

(Wolf and Dalrymple 1985, Dalrymple and Wolf 1988). Evaporites and silcretes (Dalrymple and Wolf 1988; Selleck 1978, 1984) point to elevated salinity in estuarine environments, accompanied by episodes of subaerial exposure with silica cementation.

Climate

Several authors have identified Precambrian glacial features in both Labrador (Swett 1981) and New York State (Chadwick 1920). Although not well dated, the episode responsible for these glacial features occurred at least 800 Ma ago, coincident with the latest period when eastern North America was in the high latitudes (Irving 1979). In early Cambrian time the continents were displaced such that an area extending from southern Labrador to the Gulf of Mexico lay at the Earth's equator (Morel and Irving 1978), which suggests that the much of the North American craton at that time probably had a tropical, wet climate (Ziegler et al. 1979).

The presence of Cambrian evaporites and subaerial silicification is consistent with paleogeographic reconstructions (Irving 1979, Scotese et al. 1979) that suggest that most of cratonic North America lay within 20° of the equator throughout Cambrian-Ordovician time and was subjected to high mean annual temperatures. Moreover, this was a windswept terrane lying in the hurricane latitudes in which sedimentary detritus was winnowed by strong easterly winds (Figure 6, 7).

Summary

Eastern Ontario was part of an exposed continental landmass from the Late Proterozoic to the early Middle Ordovician lying in the equatorial belt and subject to erosion and weathering in a warm, humid climate. The pre-Paleozoic interval represented by the erosion surface may be of the order of 350 Ma. Tectonically, the area lay at the edge of a continental block which began to rift and founder in the Early Paleozoic. The earliest deposits in eastern Ontario are terrestrial sediments of a wind-swept, block-faulted continent, rimmed to the south and east by shelf carbonates. The Frontenac Arch, formed by the end of the Proterozoic, continued to rise intermittently through Phanerozoic time, influencing local sedimentary deposition in the area.

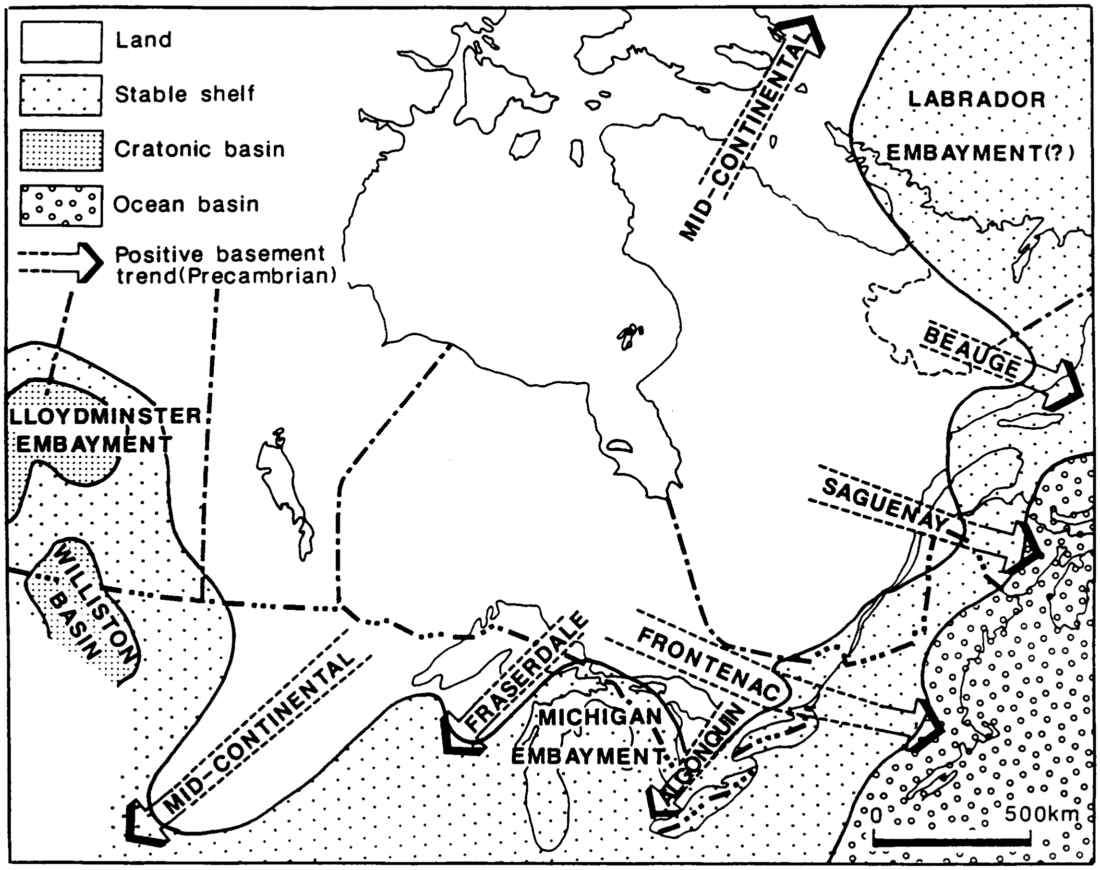


Figure 5: Rising continental areas of the Canadian Shield, Cambrian to Ordovician. From Sanford et al. (1984).

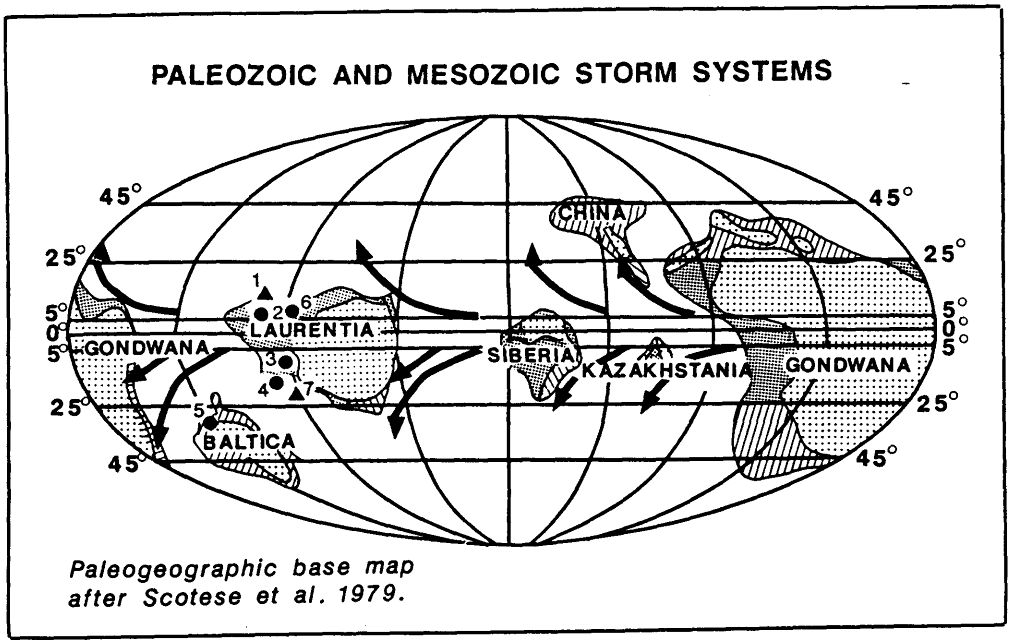


Figure 6: Hurricane pathways and storm systems proposed for the Late Cambrian. From Marsaglia and Klein (1983).

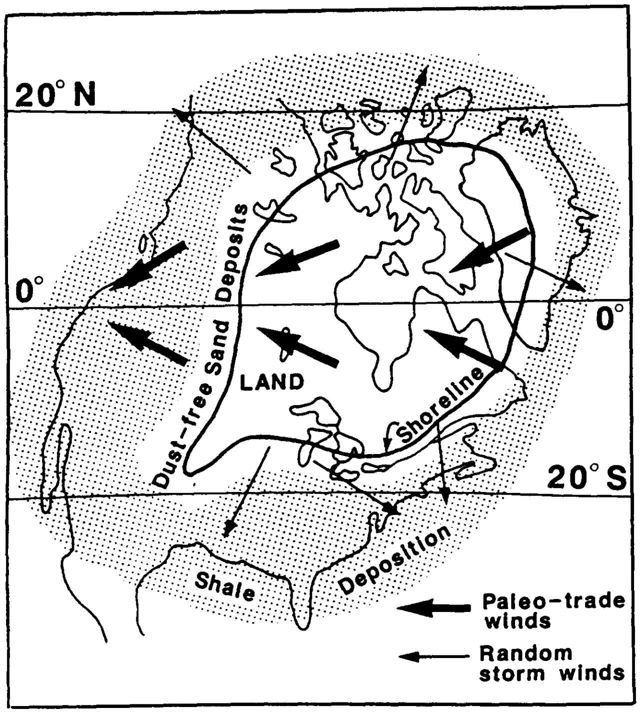


Figure 7: Wind patterns and dust winnowing over the North American craton in the Middle to Late Cambrian. From Dalrymple et al. (1985).

FEATURES CHARACTERISTIC OF UNCONFORMITIES

Introduction

Unconformities represent gaps in the geological record, and correspond to periods of non-deposition of sediments or volcanics. They result from global geological changes which may cause sea level regressions and hence, the cessation of sedimentation. Unconformities, including the Precambrian-Paleozoic unconformity in southeastern Ontario, imply that the underlying rocks were exposed in a subaerial environment and were subsequently subjected to periods of weathering and erosion. Successively younger sediments that cover the unconformity surface will be characterized by a lack of continuity between the older and younger stratigraphic units. Thus, in the field, unconformities are marked by physical discontinuities between older and younger rocks, and by features related to paleoweathering and erosion which occurred at the paleosurface.

Physical discordant contact

Physical discordant contact between an older and a younger series of rocks represent the most obvious proof of an unconformity. They are locations where "fossilized" paleoweathering and erosion features are best preserved at the unconformity surface.

Unconformity features related to a subaerial environment

At the paleosurface, features related to a subaerial environment may be preserved even when no cover rocks are present. During the period the paleosurface remained exposed, weathering processes would have affected the landmass. According to Ollier (1975) "weathering is the breakdown of materials - (minerals and rocks) - near the earth's surface to products that are more in equilibrium with newly imposed physico-chemical conditions". In many instances, the basement rocks likely formed in environments where the conditions of temperature, pressure, and the activity of oxygen and water were quite different from the conditions existing at or near the earth's surface. Low temperature and pressure, and interaction with large volumes of oxygen and water are typical of the earth's surface environment. Weathering processes are the normal sequence of events which permit geologic materials to restore their equilibrium with their environment. In practice, this occurs via chemical and mechanical actions, commonly with both interacting. Chemical processes are responsible for dissolution, transportation and redeposition of minerals and chemical elements; while mechanical processes, acting on rocks already weakened by chemical action, produce disintegration, removal, and redeposition of detritus (Table 6). Both the physical and chemical actions of weathering are responsible for erosion, and erosion and transportation of weathered materials leads to the progressive denudation and peneplanation of a landmass. Several factors influence the weathering processes, the most important being the composition and the fabric of the material affected, the paleogeography, the duration of the process(es), and the hydrologic and climatic conditions (Table 7). In practice, the remobilisation and redistribution of elements and detritus in a zone immediately below and above a paleosurface gives rise to several types of subaerial landscape. The features most commonly produced are soil profiles and karst topographies. Each of these features shows many forms. Some of the most commonly encountered are listed in Table 8,9, and illustrated in Figure 8.

As present exposures are also in a subaerial environment, they too are undergoing weathering and erosion. Thus, it can be difficult to distinguish features which are indicators of paleoweathering at a paleosurface from recent weathering effects.

At an outcrop scale, the most diagnostic characteristics of a paleosurface are weathering indicators that are anomalous for modern conditions. Another criterion for the recognition of paleoweathering is the existence of specific mineralogical phases. For example, under contemporary North American weathering conditions alteration of sulphide-bearing rocks produces hydrated iron oxides (limonite, lepidocrocite, goethite) and hydrous calcium, potassium and iron sulphates (gypsum, jarosite). Modern weathering processes follow the short lived jarosite reaction (Ross et al. 1982; Ivarson et al. 1982). In the field, white crusts or films of gypsum indicate an ongoing jarosite reaction. As this reaction stabilizes, sometimes after only a few months, it is marked by a " black cap " of goethite. Therefore, hematite, as product of alteration, is an anomalous phase if the alteration exposed on surface is interpreted as a recent post - glacial effect. In such cases, the hematite now present can be considered as a dehydrated product derived by diagenesis of limonite (Walker 1967, Ramdohr 1969, Buol et al. 1980, Duchaufour 1982). Therefore, in this instance, hematite is an indicator of paleoweathering when it appears on unconformity surfaces.

Weathering Type	**Action or Reaction Type**	**Principal Weathering Features**
Chemical weathering	* Dissolution * Oxidation and reduction * Hydration and dehydration * Hydrolysis	Karst structure Supergene reconcentrations Gossans Exfoliation and granular disintegration of rocks Laterite soil formation
Mechanical weathering	* Unloading effect * Volume change in material (produced by ice, mineralogical transformation, variation in temperature and moisture) * Abrasion (produced by wind, ice)	Sheeting Frost fragmentite Exfoliation (onion skin weathering) Collapse structures Regolith

TABLE 6: Weathering types and principal weathering features.

Host Rocks / **Climate**	**Insoluble (Granite, Volcanics)**	**Soluble (Carbonate, Evaporites)**	**Sulphide-rich Rocks and Ores**
Cold and Dry	Arctic regions, high mountains; Physical weathering dominant, rocky stony desertic landscape, shallow regolith		
Hot and Dry (Arid)	Physical weathering dominant	Duricrusts and arid soils	GOSSANS AND OXIDATION ZONES
Temperate Humid	Temperate soils and regolith	KARST	
Warm and Humid (Tropical)	Tropical regolith and lateritic weathering profile	TROPICAL KARST	

TABLE 7: Relation between prevalent host rocks, climate, and some weathering features (from Laznicka, 1988, modified)

Table 8: Soil profiles and paleosols.

Soil Profiles

* Soil profiles consist of all unconsolidated material above bedrock (Bates and Jackson 1987; definition in use in engineering geology). Soil profiles are derived from the destruction of unaltered parent rocks throughout weathering. In many instances the soil profiles correspond the whole weathering profile near the earth's surface, or they may only constitute the upper horizon of the weathered profile.

* Soil profiles are produced by mechanical and/or chemical action.

Mechanical Action Predominant

Rocky, stony, and sandy desert: (Hammada, Seris and Ergh type) Predominantly coarse clastic horizons occuring at the surface of "insoluble" rocks (plutonic, volcanic), in regions where evaporation is superior to precipitation.

Regolith: A layer or mantle of fragmental and unconsolidated rock material, whether residual or transported, and of highly varied character, that nearly everywhere forms the surface of the land and overlies or covers the bedrock (Bates and Jackson 1987). They may occur in all types of rocks in temperate to tropical regions. Their thickness ranges from a few metres in temperate regions, up to several hundred of metres in tropical areas. In paleoenvironments these detrital facies are usually cemented mostly by iron oxides, carbonates, silica.

Chemical Action Predominant

Duricrust: A hard crust on the surface of a soil in semi arid climate. It is formed by the accumulation of soluble minerals deposited by mineral-bearing waters that move upward by capillary action and evaporation (Bates and Jackson 1987). Leaching of elements may occur in all type of rocks. The most frequent elements leached are Ca, Si, Fe, which give rise to calcrete (caliche), silcrete, ferricrete. Thickness varies from a few centimetres up to tens of metres. They occur in arid to semiarid regions.

Laterite Profile: Highly weathered red subsoil or material rich in secondary oxides of iron, aluminium or both, nearly devoid of primary silicate and with quartz and kaolinite. It develops in a tropical or warm to temperate humid climate, and is a residual product of weathering (Bates and Jackson 1987). The thickness of lateritic profile may be considerable (few hundred of metres). They usually occur in tropical humid regions.

Terra Rossa: A reddish-brown residual material found as a mantle or infill over carbonate bedrock. They are residual soil in karst environment produced by the dissolution of the bedrocks. They occur in temperate to mediterranean regions.

Paleosols

* Soil profiles have occurred in modern and ancient times. Paleosols are fossilized soil profiles which have been preserved and are useful indicators of ancient paleogeography and climatic conditions. They are characterized by an abundance of resistant minerals such as quartz, kaolin, iron oxide. In some cases, buried paleosols undergo diogenetic transformations, which may result in lithification, cementation and dehydration.

Further Reading

For further information concerning soil profiles and paleosols, see: Ollier 1975, Esteban and Klappa 1983, and Laznicka 1988.

Table 9: Principal types of karst topography

Karst Topography

* The term karst is used to designate specific landforms and a geographic region characterized by these landforms. A karst is "an overprint in subaerially exposed carbonate bodies, produced and controlled by dissolution and migration of calcium carbonate in meteoric waters, occurring in a wide variety of climatic and tectonic settings, and generating a recognizable landscape (Esteban and Klappa 1983).

* The same definition applies to all types of soluble rocks (eg. evaporite).

* Karstification is a process of corrosion (by dissolution) on soluble rocks which affect an entire volume of the rock. It produces typical surface forms (exokarst) and subterranean forms (endokarst). The interaction of rocks, water, climate, topography, tectonic, gives rise to a multitude of forms. Therefore, it is not possible to present an exhaustive description of exokarstic and endokarstic forms; only the major and most typical are reviewed here.

Exokarst: All the forms of a landscape produced by the dissolution of soluble rocks. They show features from a few centimetres deep and wide to structures a few hundred metres high (or deep) and several kilometres long. There is a large range of transitional forms between karstic structures and soil profiles (caliche) in carbonate rocks.

Microtextured surfaces:

Essentially a surface phenomenon producing an irregular surface of a few centimetres of relief. Etched, pitted scallopped surfaces, grooves, ripple patterns.

Textured surfaces:

Mostly a surface phenomenon which may have links with deeper karst zones. Scale: a few dozen centimetres to a few metres deep and wide.
A vast range of regular to irregular circular to elongated hollows formed by dissolution and named Karren (or Lapies). Special pillar type forms are called pinnacled structures.

Depression surfaces:

Dissolution of greater quantity of material resulting in large scale modification of the original topography. From several dozen metres to several kilometres.
These depression shaped structures have a connection with the deeper karst system; they are the manifestation at surface of endokarstic structures. Sink holes (swellet) - Dolines - Cenotes - Poljes - Karst valley.

Endokarst: (Underground system)
Imbricated, complex system of water flow passages which is made up of caves, pipes, tubes, dissolution shelves, from a few centimetres to several hundred metres wide and commonly many kilometres long. The mechanisms of dissolution and precipitation underground produce: speleothems (stalagmites, stalactites, "cave pearls", "flowstone") and collapse structures. An idealized cross section of an underground karst system, is illustrated in Figure 8.

Paleokarst

Karst topographies may be preserved when burried under younger sediments. They can undergo diagenesis (such as compaction, cementation, recrystallization, dehydration) which may modify the original appearance and characteristics of the karst structures.
Exokarstic structures at the paleosurface are best "fossilized" and preserved. However endokarstic forms (sink holes, pipes) and collapse structures may also be preserved.

Further Reading

For further information, see: Ollier 1975, Bogli 1980, Sweeting 1981, Esteban and Klappa 1983.

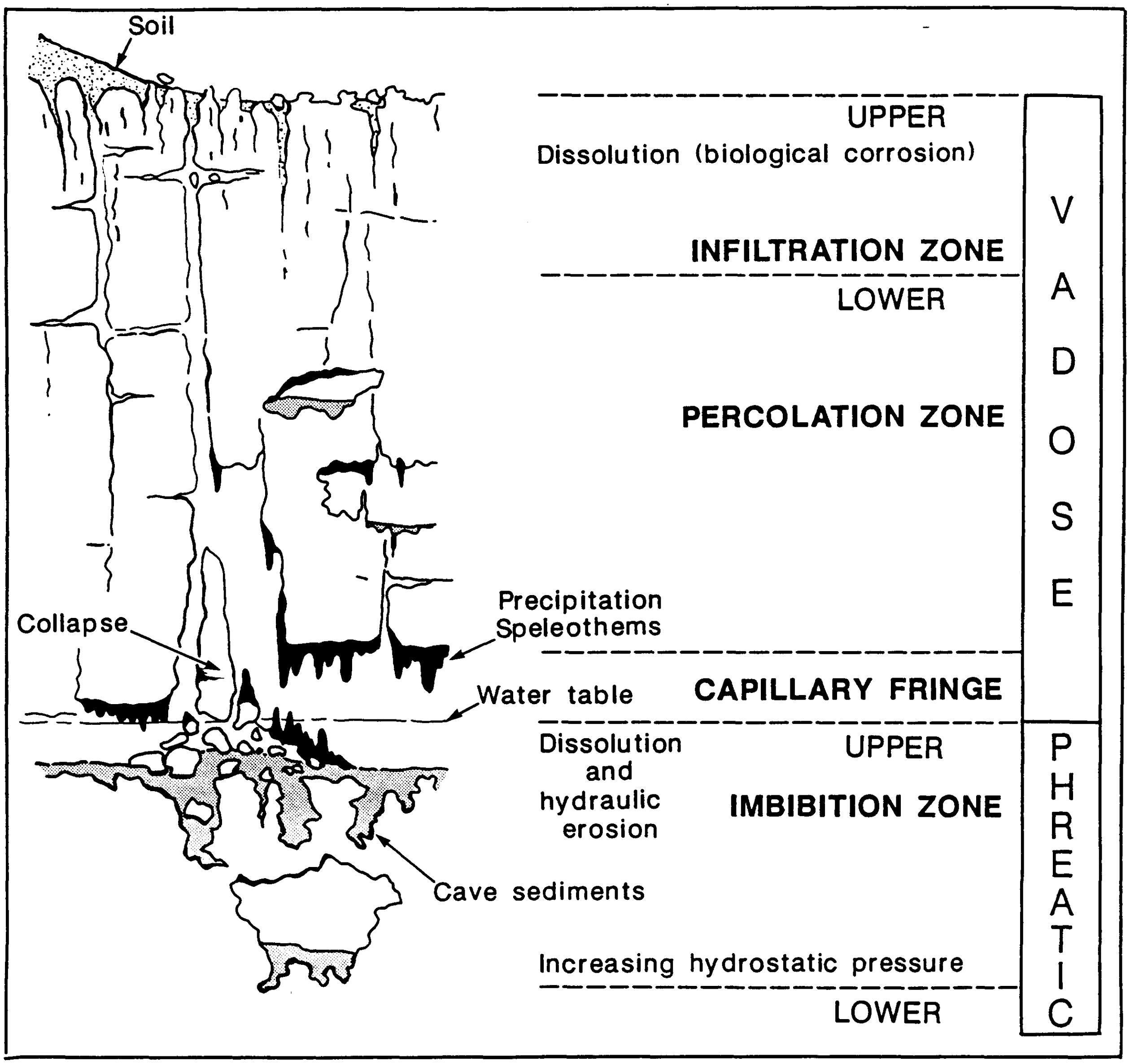


Figure 8: Idealized karst system. Modified from Esteban and Klappa (1983).

MINERALIZATION ASSOCIATED WITH UNCONFORMITIES

Overview

There are several discrete geological environments associated with unconformities which can be used in guiding exploration.

Where weathered profiles have been preserved there may be concentration of secondary mineralization (Au, Ag, Mn, Fe, Al, Cu, Ni, U, Si). Pre-existing mineralization in the basement as well as the secondary supergene occurrences may be mechanically reconcentrated preferentially in topographically low locations (Figure 9, Table 10). Oxide mineralization of Fe, Si, Pb, Zn and occurrences of fluorite, barite, phosphate may form.

In soil profiles the most favourable horizon for epigenetic mineral enrichment will be close to the interface with the basement rocks. There will also be variations that reflect the paleotopography; the highest ore grade can be expected in paleodepressions.

The primary processes of weathering are also responsible for lasting changes in the immediate physical environment, manifested by an increase of the open space in the host rocks. Ground preparation is most effective in carbonate terranes where the karstification can provide an extensive and deep system of hollow space in which mineralization may occur (Figures 8, 10, Table 11). The relations between karst and various types of mineralization are illustrated in Figure 10 and Table 11.

The activity in the karst zones does not end when the erosion surface is buried by younger later deposits. Karst horizons are zones for fluid circulation that may have been active throughout long periods of time, right up to modern time. Environments like these may become sites for mineral deposition whenever element-enriched fluids flow through the rocks. This commonly happens when there is a regional rise of the water table in connection with eustatic changes in the sea level, or when there is upward welling of basinal brines under diagenetic effects.

Details

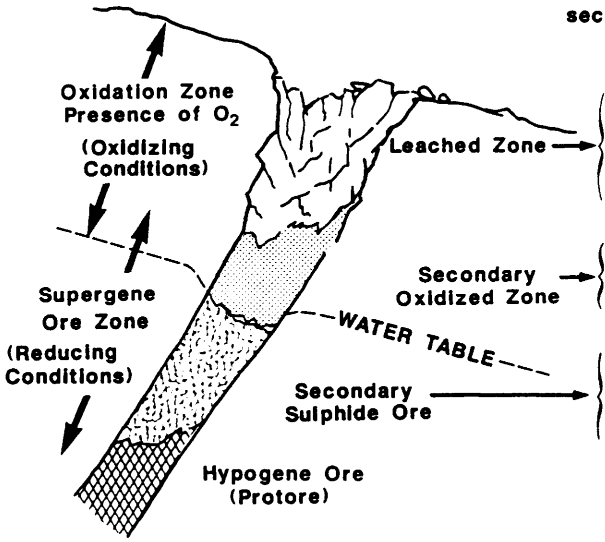
Mineral occurences at unconformities may arise from the primary processes which affect the paleosurface (peneplain). Weathering assists in the concentration of metals; however the concentration of metals (the Clarke value) must already be high in the bedrock in order to obtain, via weathering, concentrations of economic importance. In areas where anomalous Clarke values already occur in the basement rocks, ore deposits may occur in the weathering profiles produced by soil forming mechanisms (Figure 9, Table 10), or in the residual or transported mineralized detrital blanket (regolith) above erosion surfaces (Figure 9, Table 10). Because of the interplay of other factors, including physiography and tectonics, many districts show a wide range of metallogenic settings which encompass both chemically and physically produced mineralization (Table 10).

When sulphide ore deposits, or sulphide-rich rocks, occur near the surface, strong weathering may lead to supergene enrichment of minerals and typical "zoned" structures (Figure 9). Weathering of carbonate or other soluble rocks can form karst topographies which may in turn be mineralized.

In karst systems, the primary processes of weathering at unconformity surfaces produces irreversible modifications in the permeability and porosity of the basement rocks, typified by a general increase of open spaces immediately below and above the erosion plane. This ground preparation provides a plumbing system which is active before, as well as after, the basement has been buried by cover rocks. Thus, epigenetic ores may occur in the structures produced by processes of subaerial weathering. Karst structures act as pathways for mineralizing fluids and, in some cases, as traps for minerals. Minerals may precipitate repeatedly in these structures at any time after they are formed, and may occur below, along, and above the unconformity (Figure 8, 10).

If the burial of the paleosurface is shallow, the mineralized weathering profiles will not undergo major any post-depositional modifications. However, under thicker cover, burial subjects the pre-existing structures and mineralization to diagenetic modifications such as compaction, dehydratation, mineralogical changes which can produce lasting changes in the mineralized weathering profiles (Table 10). Diagenetic processes not only affect pre-existing mineralization at unconformity surfaces, they may also be responsible for the formation of new mineral occurrences, whose formation and deposition is controlled by the unconformity. Such occurrences are widespread in the world and include some types of stratiform ore deposits in carbonate rocks, and unconformity-type uranium deposits (Table 10).

A mature gossan profile (weathering profile above sulphide-rich rocks) is the result of thorough and uninterrupted weathering (mostly chemical). It is composed of a leached zone (rich in iron oxides, silica, resistates), an underlying zone of secondary ore minerals (oxides, carbonates, silicate) and a deeper zone of secondary supergene sulphide over the protore.



Oxidation of Primary Ore:
Volume reduction and released of sulphuric acid.
Loosening and shrinkage of the bed rock and ore at the surface of the weathering profile.
Collapse and gravity accumulation of resistates, fragments, and clay (mixing of iron oxides and silica).
Minerals resistates (Gold, Ilmenite, Barite ...) are mechanically concentrated and enriched.

Supergene mineralization formed in the zone of oxidation.
With predominantely silicate wall rock, oxide or silicate ores will preferentially occur.
In carbonate host rocks, acid solutions would be neutralized and carbonate ore will form.

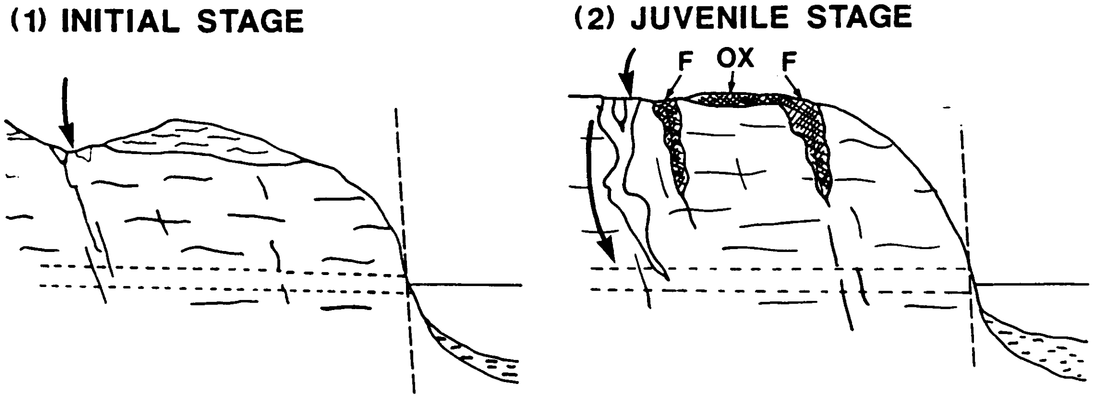
Supergene sulphide ores form in reducing environmemt.
Where high quatity of sulphides are available, leached ions are carried in strongly acid solution, deep in the reducing zone. In ore deposit with lower content of sulphide most of the supergene ore will be precipited in the zone of oxidation.

Weathering produce enrichments of high and low grade ores and weakly dispersed minerals. A few examples include:

- Chalcocite enrichment above porphyr copper deposits - La Caridad, Mexico, Saegart, Sell and Kilpatrick 1974.
- Supergene silver concentration of sulphides and oxides - the "Bonanza" ore, "Horn silver" mine, USA.
- Secondary gold silver enrichments - Western Australia district, Webster and Mann 1984; Pueblo Viego, Dominican Republic, Russell et al.1981.

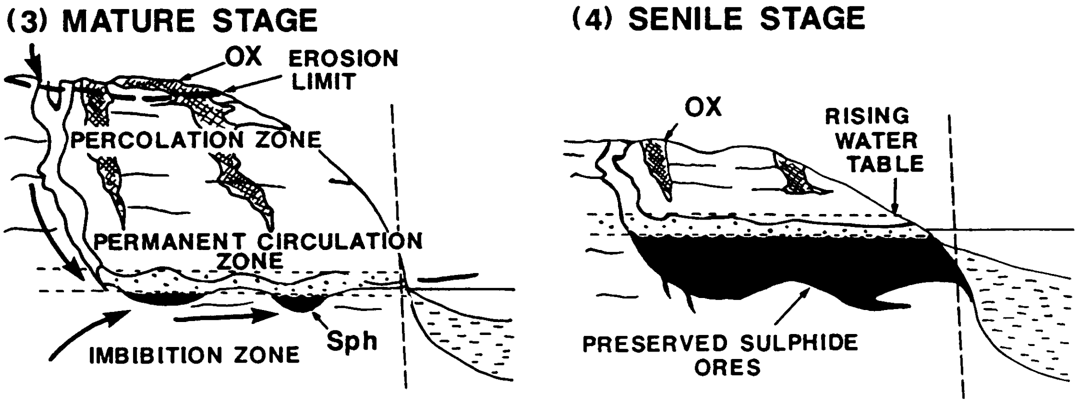
Figure 9: Idealized weathering profile above sulphide-rich rocks or veins.

Figure 10: Evolution of a karst terrain and its mineral deposits.



(1) Aggressive waters reach the inlets of a fissure system in a permeable carbonate complex. A karstified surface with pits, dolines, sink-holes starts developing.

(2) Dissolution produces a weakening of the rock fabric, cavity development proceeds in depth producing sub-vertical solutions cavities (pipe-like), until a water table or an impermeable stratum is reached.
Oxidized ores (Ox) are formed in the percolation zone, along preexisting structural planes enlarged by solution.



(3) As the system matures, cavity development proceeds along the water table or the impermeable stratum. Stronger dissolution and weakening of the rock fabric result in collapse and breccia formation and sub-horizontal tunnel-like cavities develop.
Sulphide mineralization (Sph) occurs occurs below the water table in the zone of permanent circulation (imbibition zone), meanwhile, close to surface, part of the oxide ores (Ox) are removed by erosion.

(4) In the senile stage, a levelling of the system is reached. The imbibition zone thickness increases as the water table rises.
Beneath the water table, thick sulphide ores (Sph) are preserved, while sub-surface oxide ores are still removed by erosion.

(From Zuffardi 1976, modified)

Karstification can provide an extensive and deep system of hollow spaces in which mineralization may formed. The ores will be typically depth stratified.
* In the uppermost Percolation Zone, oxide ores (Ox) are typically developed and ore bodies will follow fracture patterns and water flow gradients, so they will be steeply dipping to vertical.
* In the Imbibition Zone, below the water table, massive sulphide deposits (Sph) with a sub-horizontal body shape occur.
*The intermediate zone, above the water table, is complex, showing many generations of sulphides and oxides overprinting one another, in response to variations in the water table.

Table 10: Types of Ore Deposits related to unconformities

Mineralization Type	Deposit Name	Environment and Characteristics
Laterization of erosion surface	Mount Goldsworthy Mine, Pilbara Province Western Australia, (Neale 1975)	Hematite enrichement of Precambrian banded iron formation. Dense hematite ore body formed by secondary enrichment above an Archean banded iron formation. Formation in a tropical environment of a thick, chemically formed, mineralized weathering profile on an old erosion surface.
	(Le Count Evans 1981)	Laterization of old erosion surface may reconcentrate gold (French Guiana), addition of Fe,Mn, Ni.
Detrital ore reconcentration	Cape York Peninsula- NE Queensland, Australia (Evans 1975)	Residual bauxite blankets. Extensive blanket of residual Al-rich minerals overlies Tertiary sediments. Formation of mechanically concentrated detrital mineralized weathering profiles above an erosion surface.
	Witwatersrand basin South Africa (Pretorius 1975; Button & Tyler 1981)	Detrital accumulation of minerals in a fan. Early Proterozoic paleoplacer containing uranium, gold, platinum, occurring on an Archean erosion surface. Some mineralization formed as a result of mechanical weathering and transportation by water.
Chemical and mechanical secondary ore reconcentrations	Quadrilatero Ferrifero, Minas Gerais, Brazil (Dorr 1969)	*Occurrence of high grade "secondary" iron enrichment (specularite, hematite) above Proterozoic siliceous banded iron formation (Itabirite) *Occurrence of lithified surface or near-surface rocks composed of varied quantities of detrital ore fragments cemented by goethite to form a blanket-type body (Canga) on the Precambrian erosion surface.

Table 10: continued

Mineralization Type	Deposit Name	Environment and Characteristics
Modified, or new, ore deposits formed by postburial diagenesis in the zone of the unconformity	Belgorod District West Central USSR, (Kirpal & Tenyakov 1974)	Modified buried bauxite deposit. Mineralized weathering profiles (Al-rich) occur on Proterozoic metasediment and interbedded banded iron formation. The Proterozoic basement is buried under lower Carboniferous cover. The ore consists of residual bauxite horizons, where Al-rich minerals have been altered by diagenesis (e.g. gibbsite to boehmite).
	Zambian Copperbelt, Central Africa (Button & Tyler 1981; Morganti 1988)	Stratiform ore deposit related to unconformity. Marine intracratonic sediments cover granitic Precambrian basement. Groundwater circulating through a paleosol, above the erosion surface, controls the distribution of copper around paleohills.
	Western USA; Westmorland, Australia (Tilsley 1988)	Sandstone-hosted ore. "Roll-Front" or Tabular uranium deposits". Chemical weathering leaches metals at paleosurface. Metals are carried in solution by groundwater into sediments covering the paleosurface where oxidizing solutions precipitate metals at oxidation-reduction front. Mostly in Mesozoic and Cenozoic sediments.
	Athabasca deposit, northern Saskatchewan, Canada Northern Territory of Australia (Marmont 1988)	Unconformity-type Uranium deposits. Deposits occur at the Early to Middle Proterozoic boundary just above or below unconformities and are hosted by different lithologies and types of structures. Weathering, erosion and subsequent diagenesis have contributed to the formation of these deposits.
	Central and east Tennessee; Upper Mississippi River Valley, USA; Pine Point, NWT, Canada (Mills and Eyrich 1966, Anderson & Macqueen 1988)	Mississippi Valley Type deposits. Mineralization (sulphide, oxide) occurs in different types of structure, close to buried unconformity. Basinal fluids use the permeable unconformity "zone" as pathways and as traps. Ground preparation at unconformity "zone" channeled and trapped upward-welling basinal brines.

Table 11: Karst Related Mineralization

* Metallogeny related to karst systems is complex. There are many variations and transitions with other metallogenic settings. Most of the deposits occurring in the karst system are produced by regeneration and, or entrapment of ore generated earlier; therefore the notion of "metal heritage" is important. Most of the time, karsts provide only the open spaces for ore deposition. Infilling of such open spaces may take place during the active period of karst developing or well after its maturation and burial (paleokarst).

* Usually, the upper zone of the karst (percolation zone) traps detrital oxide ore (or native metal) in karst generated depressions occurring during the active period of karst development (eg. 1,2,3). (However ore minerals accumulated in the imbibition zone, coeval with karsting are known, e.g. 4). In contrast, the imbibition zone hosts precipitated sulphide ores which occur, most of the time, well after the maturation and burial of the karst (e.g. 5, 6) (mineralized paleokarst).

* In eroded area, the sulphide ore in the imbibition zone will better preserved that the subsurface oxide ores.

For further information, see: Quinlan 1972, Zuffardi 1976, Laznicka 1985, 1988.

Mineralzation Type	**Deposit Name**	**Environment and Characteristics**
Mineral-rich material infills-surficial karst depression	1) Guadalcazar (San Luis Potasi state), Mexico (Foshag & Fries 1942)	Weathering residues derived from a mineralized granodiorite were washed into karst depressions developed on Mesozoic limestone. Heavy minerals recovered include cassiterite, Ag-sulphides, gold.
	2) Yunnan district southern China (Searls 1952)	Lag residual deposits of Pb-Zn sulphides blocks, derived from the carbonate rocks, occur in the debris-filled sinkholes over the same carbonates.
	3) Kuranakh (Yaltia) USSR (Pustovalov 1965)	Mineralized clay derived from Cambrian rocks infills karst depressions. The infill consists of clay, rock fragments, quartz, silicified carbonates, and irregularly distributed gold.
Epigenetic mineralization filling cavities in lower zones of the karst	4) western Nfld., Canada (Collins & Canada Smith 1972; Smith Collins 1971)	Zinc mineralization was leached from the upper part of the the carbonate sequence and penecontemporaneously redeposited in open spaces of the lower karst system.
	5) Salafossa, central Alps, Italy (Bernard et al. 1972)	Mineralized paleokarst in Triassic carbonates. Sulphide cement (sphalerite) in a well developed imbibition zone. Mineralization occurs as breccia matrix and fill of cavities under the breccia.
	6) Kingsport Fm. and Mascot Dolomite, E Tennessee, USA (Harris 1971)	Sulphide deposit occurs in previously barren karst system in Lower Ordovician carbonates. After burial the paleoaquifer was flooded by a rising water table which deposited economic concentrations of zinc.

THE PRECAMBRIAN-PALEOZOIC UNCONFORMITY IN SOUTHEASTERN ONTARIO

Introduction

The Precambrian-Paleozoic unconformity in southeastern Ontario represents a gap in the sedimentary record of several hundred million years. A paleosurface ranging in age from about 700 to 470 Ma is developed on intrusive, volcanic, and clastic and carbonate metasedimentary rocks. During this period, weathering and erosion in a subaerial environment affected the exposed Precambrian bedrock. For more than one hundred years, distinctive features that mark the erosion surface above Precambrian rocks, have been recognized by various workers as manifestations of paleoweathering on an exhumed Precambrian paleosurface (Table 12).

Signature of the unconformity in the field

In southeastern Ontario the unconformity, that occurs between flat-lying unmetamorphosed Middle Ordovician sediments and the basement rocks (Figure 11), is characterized by a variety of paleoweathering features (red hematite mineralization, textured surfaces, endokarstic dissolution forms, residual soils). These features are described in detail in the Appendix of this report, and the sites are shown on the Map (back pocket). What follows here is a brief description of the types of features observed by the authors along the Precambrian-Paleozoic unconformity.

Under present North American climatic conditions, hematite at the unconformity surface is anomalous and can be explained as rubification as iron-enriched horizons undergo diagenetic alteration (Walker 1967, Buol et al. 1980, Duchaufour 1982). Examples of this process, in which there is progressive release and oxidation-hydration of iron, are reported from subaerial weathering surfaces of various epochs (Feakes and Retallack 1988, Ettensohn et al. 1988). In southeastern Ontario, red staining of the Precambrian rocks may take the form of hematitic coating on fracture planes (Appendix, occurrence 1,4,5), as hematite-calcite veins (Appendix, occurrence 2), or as the alteration of iron minerals in the Precambrian rocks (Appendix, occurrence 3). There is also iron enrichment in loose residual materials (terra rossa) which are left after selective removal of calcium carbonate from carbonate rocks, particularly dolomite (Appendix, occurrence 4).

Close inspection of suspected paleosurfaces shows a micromorphology on the basement in which typically a very small thickness of Paleozoic material (less than 1 cm) is preserved (Appendix, occurrence 5). Glaciated surfaces which have been weathered in modern time still appear very smooth and fresh; by contrast exhumed pre-Paleozoic surfaces have a pronounced texture which suggest a longer and more intense weathering. For example on vertically standing slates (Appendix, occurrence 1) a micromorphology of about 2 cm deep is developed. Glaciated surfaces in the same rocks are virtually smooth.

Loose blocks of metadolerite on depressions at the paleosurfaces (Appendix, occurrence 6) show spheroidal (onion skin) weathering patterns that, in the study area, can be best explained as the result of tropical weathering. Spheroidal weathering is particularly developed in basic intrusive rocks because of the nature of fracture pattern in these rocks.

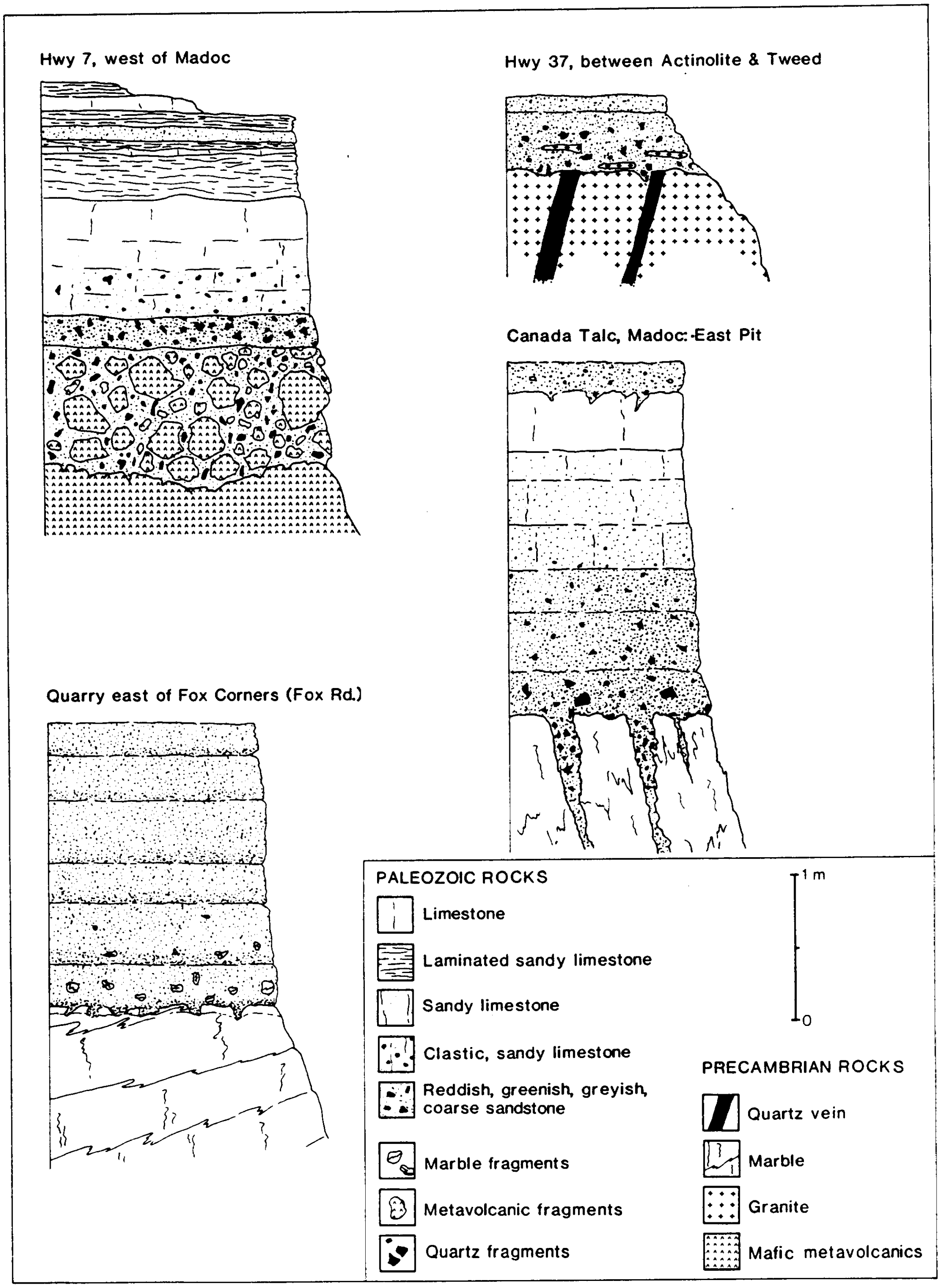
Another type of fracture is "sheeting" developed immediately below the unconformity plane and subparallel to it. It has been produced by gravity unloading effect in pre-Paleozoic times (Appendix, occurrence 7). It is a secondary fabric, largely horizontal, which mostly cross cuts the upright fabric of the basement rocks. This " sheeting " is more common in granite and marble. At occurrence 7, the intersection of the metamorphic foliation with the secondary sheeting fabric is responsible for the formation of residual rock slabs of various sizes.

In carbonate rocks the pre-existing fracture pattern and " sheeting " allows rapid removal of calcium carbonate, initiating development of a karst system. At the paleosurface, karst features include; vertical caverns several metres deep (Appendix, occurrence 3), small oval pits (kamenitza) in selected horizons of calcareous marble (Appendix, occurrences 3, 8) and etched surfaces with furrows 1-2 cm deep (Appendix, occurrences 1). In fracture zones, particularly in the more competent dolomites, dissolution has produced a characteristic pinnacled paleotopography where selective erosion on fracture planes has left a jagged pillared surface several metres high (Appendix, occurrence 9).

Karst in calcitic marble is different from karst in dolomitic marble. In calcitic marble, erosion produces typically smooth karst forms controlled by a fracture pattern and metamorphic foliation (Appendix, occurrence 10). In contrast dolomitic marble is more brittle and the leaching of calcium carbonate leaves residues and highly permeable collapse structures (Appendix, occurrence 4).

Although residual soil profiles are particularly well preserved in zones of strongly fractured carbonates, there are residual soils associated with many kinds of basement rocks. The profiles which we have interpreted as paleosols compare very closely with their modern equivalents. The major features they show are textural, and include; crumb-like structure, a general increase of the porosity, and a general increase of resistant minerals residues (quartz, tourmaline) (Appendix, occurrence 3).

Figure 11: Unconformity surfaces from the Madoc-Marmora area, illustrating differences in Precambrian weathering surfaces and the basal Paleozoic sediments in the study area.



The weather residues appear amorphous but are commonly overprinted with secondary horizontal pseudo-layering (Appendix, occurrences 12,13). They are coloured differently than the bedrock (Appendix, occurrences 12,13). At first glance they appear to be soft but they are partially to completly lithified by the addition of cement(s) which include calcium carbonate, silica, and/or iron oxides (Appendix, occurrences 14, 20).

Mineralization and the Precambrian-Paleozoic unconformity in southeastern Ontario

When compared to the global models of mineralization outlined in a preceeding section, mineralization related to the Precambrian-Paleozoic unconformity in southeastern Ontario can be divided into two categories; namely:

I - mineralization directly produced by the processes of weathering, and
II - mineralization indirectly related to the unconformity.

Most known deposits from the study area are of the first type.

The latter type exists because of the presence of the unconformity, and the secondary effects of the unconformity on the geological environment, such as increasing the porosity and permeability of rocks (ground preparation), thereby providing preferential ore-bearing fluid circulation pathways.

Since the turn of the century, various workers have noted a direct or indirect association between some ore deposits and the Precambrian-Paleozoic unconformity (Table 13).

Table 12: Overview of observations on paleoweathering and paleosurfaces in eastern Ontario and the North American Shield

Evidence of subaerial erosion surface and effect of subaerial weathering	References
* Oxidation of the Precambrian bedrock at the paleosurface. Paleosurface winnowed. Mineralogical changes due to the weathering (kaolinization, chloritization)	Murray 1853, Bell 1894, Baker 1916, 1922, 1939, Wright 1923, Hewiit 1964a
* Dissolution of Precambrian carbonate at the erosion surface	Kavanagh 1889, Hawley and Hart 1934, Dietrich 1954, Selleck 1978, Dalrymple and Wolf 1988
* Comprehensive discussion of the evidence for a subaerial pre-Paleozoic weathering event	Dix 1947
Evidence of an exhumed pre-Paleozoic surface	
* Recognition of an intact paleosurface, Saguenay area, Quebec	Laflamme 1895
* Recognition of pre-Glaciation, pre-Paleozoic hummocky surfaces in Ontario, Quebec, and Labrador	Lawson 1890
* Comprehensive summary of peneplains (paleoplains) of the North American Precambrian shield; and recognition of pre-Cambrian "roche moutonee".	Ambrose 1964
* Recognition of valloned paleosurface (up to 300 m of relief).	Hewiit 1964a

Table 13: Relationship of mineral deposits to unconformity, paleosurface - historical observations

AUTHOR	OBSERVATION	STATED INTERPRETATION
MacFarlane 1866	Conglomeratic hematite boulders in alluvium: on high ground; 45 cm thick on limestone. Veins of hematite in porphyry calcite-barite-chlorite schist breccia cemented with chalcopyrite	Hematite is Laurentian (Grenvillian) in age; ice-transported to 56°-18°W
Vennor 1870	"Seymour iron ore bed covered by unconformable Lower Silurian." Wallbridge iron mine was reportedly in a depression filled with hematite. It contained loose hematite masses up to 50 kg in weight. Spectacular veins of hematite cut chlorite schist on west shore of Belmont Lake (Con. 5 lot 8)	Hematite occurred in a topographic low, a cavity below the Paleozoic unconformity
	Richardson property: native gold in chalcopyrite vein cutting chlorite-epidote gneiss, overlain by ferruginous dolomite. Observed "a longitudinal ovoid crevice 4 feet below surface, filled with ferruginous earth.... scattered black carbonaceous matter... showing flakes or scales of gold." The crevice and infill was located in schist at junction to dolomite, conformable to stratification. Another crevice was found at 5m down (by inference, down the plane of thelithology)	Not a true vein, but crevices confined to a particular horizon. Gold at junction of mica slate and dolomite
	Vennor reported: "Small openings filled with ferruginous earth in which gold was detected"; an opening, circular in cross-section, 18' across stratification and included in the dolomite "contains black carbonaceous matter, brown ferruginuous earth, gold in dolomite, calcspar."	These cavities may be a key to both iron and gold deposits
Blue 1894	Belmont mine; (A) E-W vein (Main) consists of quartz with pyrite, chalcopyrite Blue reports: "for some depth from surface the vein is decomposed into earthy iron-oxide, and with siliceous matter. The decomposed matter pans (for gold) richly throughout". Open cavities down to 122'. Assayed (1894) $16/ton at this depth.	The sulphide ore is oxidized near surface Free gold is associated with limonitic earths derived from weathered sulphides

Table 13: continued

AUTHOR	OBSERVATION	STATED INTERPRETATION
	b) <u>Centre vein:</u> "oxidized earthy matter gave $5 a ton" (1894). Ledyard Mine "at 45' depth, pyrite, chalcopyrite was found in cavities showing free gold." Pyrite is altered to limonite with free gold".	-
Slaght 1898	Diamond Mine: "Quartz vein with free gold. Decomposed material down a few feet from surface gave a rich showing of free gold".	
Corkill 1906	Eldorado Copper Mine: "at 75' (depth) chalcopyrite displaces hematite. The ore body is between granite and crystalline limestone".	
Wilson 1929	Lack of wall rock alteration, absence of chill margin on Paleozoic host rocks	
Gibson 1937	Eldorado copper mine	Effects of oxidation seen. At surface the ore was hematite; at 20-30 m it was found to be altered from chalcopyrite
	Richardson gold mine	Downward surface enrichment in Precambrian time. Later covered by Paleozoic limestone which protected the Precambrian from erosion
Rose 1958	Replacement of magnetite, chalcopyrite by hematite near surface surface. Fragments of hematized magnetite enclosed in basal Paleozoic conglomerate	Hematite is a weathering product formed within 60 m downward from the present or pre-Paleozoic surface. Hematite may develop from chalcopyrite or magnetite by pseudomorphy. This replacement is pre-Paleozoic.
Guillet 1962	Olympus mine, Stanleyville friable, strongly weathered rocks host vermiculite	Beneath Potsdam sandstone (Cambrian) there is a deeply weathered surface. Most weathering was pre-Paleozoic.

Table 13: continued.

AUTHOR	OBSERVATION	STATED INTERPRETATION
Guillet 1964	Madoc fluorite deposits are post-Ordovician veins: Lenticular cavities in fault zones, filled with fluorite-calcite-barite and minor sulphides. Crustiform, open space fillings cement brecciated Grenvillian and Paleozoic rocks.	post-Ordovician, low-temperature veins filling open spaces along fault places
	"Gravel spar" (friable fluorite-calcite) above water table and dark hydrocarbons present (Wilson 1929)	Modern weathering above water table
Sangster and . Bourne 1982	Post-Ordovician veins: No known post-Ordovician magmatic activity in SE Grenville. Low temperature (122° - 132° C) veins. More veins in Grenville than in Paleozoic	Post-Ordovician emplacement by circulating meteoric waters. Spatially related to Paleozoic unconformity.
Carter 1984	Post-Ordovician veins: Simple mineralogy; open space fillings; low temperature. Fault-related; close to Paleozoic unconformity.	Contemporaneous with the Ottawa-Bonnechere graben (Cretaceous). Permeable sandstones at the base of Paleozoic rocks acted as aquifers for brines moving from Paleozoic basins. These vein deposits arise by percolation of iron-rich water into fractures and porous zones; subsequent deposition of iron as hematite. Age 500-600 Ma
	Hematite concentrations: a) disseminated in basal Cambrian (Potsdam) sandstone b) confined to fractures in Paleozoic limestone or Grenville marble	
Mackinnon et al. 1985	Olympus Mine, Stanleyville. Vermiculite occurs in strongly weathered rocks Iron content increases toward surface	A post-Grenvillian, pre-Nepean weathering event may have influenced vermiculite formation and the distribution of iron.

Type I Mineralization (Table 14)

One major expression of weathering at the unconformity is the oxidation of minerals. In such instances, mineralization located in the uppermost horizon of the oxidation zone, closest to the erosion surface, in which metals have been leached and transported downward, is exmplified by resistant residual ores such as iron and manganese oxides, silica, and in some cases, gold.

In situ chemical and mechanical action above Precambrian ore deposits during the Late Proterozoic and the Early Paleozoic has yielded iron-enrichment in gossans (Appendix, occurrence 15). In a few localities the oxidized zone is very extensive, and oxide mineralization occurs in structures which are interpreted to be lateritic profiles (Appendix, occurrence 16). Manganese oxide deposits occur locally, and commonly are associated with iron. Both iron and manganese have been leached from the Precambrian carbonate rocks (Appendix, occurrence 17). Oxidation above Precambrian quartz-sulphide-gold bearing veins, in the uppermost leached horizon, locally has yielded secondary gold enrichment (Di Prisco and Springer 1988) (Appendix, occurrences 18,19).

In the above cases, mechanical and chemical action are equal, and secondary supergene mineralization has formed. However, if in situ mechanical action prevails, thick detrital blankets (regolith) develop. Erosion surfaces that cut across Precambrian ore deposits, for example iron skarns, are commonly mantled by iron and sulphide clast conglomerates (Appendix, occurrences 14, 20). In a few places, these paleoregoliths are latter enriched in iron oxide, carbonate and silica, the effect of groundwater (Appendix, occurrences 14, 20).

The unconformity on Precambrian carbonate rocks is marked by karst structures, and epigenetic mineralization is trapped in open spaces related to the dissolution of the rocks. Mineralization is found in thin crevices (Appendix, occurrence 21) and small cavities (Appendix, occurrence 22) very close to the paleosurface, or in larger open spaces a few metres below the Precambrian erosion plane. Mineralization has precipitated into these open spaces (Appendix, occurrences 3, 23), which also host later Paleozoic epiclastic mineralized sediments (Appendix, occurrence 3). The mineral occurrences are located in the upper part of the karst system (percolation zone), and are usually characterized by oxidized minerals. Deeper systems, which may be present may prove to be richer in sulphide ore.

Table 14: Mineralization related to the Precambrian-Paleozoic unconformity in southeastern Ontario

	Ore Deposit Type	Locality type and Map Number
Mineralization at the unconformity surface, directly related to paleoweathering and erosion	*Oxide ore reconcentrated at the paleosurface produced predominantly by chemical weathering of basement rocks and, or sulphide-rich rocks. Principal elements reconcentrated are: calcium silica, iron, manganese, gold. Typical structures are gossans, laterite, ferricrust.	Canada Talc Mine (3), Wallbridge iron mine (14), Coe mine (15), Furnace Falls occurrence (16), Mono Gold Mine (17), Blairton iron mine (20)
	*Minerals reconcentrated in the upper leached zone of weathered Precambrian veins. Principal minerals reconcentrated are iron oxides (red earths), gold.	Cordova (18) & Diamond gold mines (19)
	*Mineralized paleosols, mechanically reconcentrated at the paleosurface. Mineralized paleoregoliths containing fragments (14, 20, 20'). Lag residues at the paleosurface (3).	Canada Talc Mine (3), Wallbridge iron mine(14), Blairton iron mine (20), Dufferin Iron Mine (20')
Karst Mineralization	*Mineral reconcentration in karst hollows (dissolution cavities) ties) at, or underneath the Precambrian paleosurface filled contemporaneously or post-karstification. The pricipal minerals reconcentrated are carbonate, oxide sulphide; and the principal metals reconcentrated are Ca, Fe, Cu, Au, U.	Canada Talc Mine (3), Hazards Corner Occurrence (22), Richardson gold mine (23)
Mineral deposits spatialy related to the unconformity and mineral occurrences indirectly controlled by the unconformity	*Secondary cementation or infilling of open spaces and veins at, or close to the unconformity surface; likely occurring after burial of the paleosurface (except karst hollows)	Wallbridge Iron Mine (14), Blairton Iron Mine (20), Blakely (24), Hollandia (25), Noyes Mine (26), Cordova Village north occurrence (27)

Type II Mineralization (Table 14)

Several types of veins, indirectly controlled by the unconformity, occur in fractured zones along and adjacent to the unconformity and in fractures in the Paleozoic rocks. These are probably cases of mineralization indirectly related to the unconformity.

Discussion and Implications

Review of global examples of mineralization associated with unconformities has provided us with several types of metallogenesis related to unconformities. In southeastern Ontario, some types of mineralization are fully developed, and others only partially or not at all. What does this mean for the mineral potential to be found in this area? Are there ore deposits still hidden?

There is field evidence that secondary reconcentration has been active on the erosion surface. But because the landsurface was reworked by the Ordovician marine transgression and subsequently by Pleistocene glaciation, the thick weathered mantle that possibly covered the old shield is almost completely absent in southeastern Ontario. However, there is a considerable paleotopography on this old surface, and the weathering mantle is still preserved in paleodepressions which themselves reflect the interplay of lithology, competence, and fracture patterns. For example, where rocks are deeply fractured, one may expect to find paleovalleys in which supergene reconcentration will be more readily preserved.

Today's exhumed landsurface, which has been scraped clean, gives a false impression thar little mineralization is present because we are looking mostly at paleohilltops. In contrast, the low points in the paleotopography are the key areas for supergene reconcentration. Paleotopographic lows are places where fluid flow has been channeled; where gravity will have mechanically concentrated ores; and finally where unconformity features, with or without ore, will be best preserved. Mineralized paleoregoliths in topographic lows have already been found (Wallbridge iron mine, occurrence 14; Blairton iron mine, occurrence 20). Other lithified paleoregoliths, which may extend deeply underneath the soft hematitized capping usually found on surface above gossans, can also be expected in paleovalleys.

We have evidence of in situ reworking of residual or altered material, but no evidence of material reworked by the effect of water transportion in pre-Middle Ordovician time. However we do know that "wadi" deposits were formed in pre-Postdam time on the land surface in southeastern Ontario (Dalrymple and Wolf 1988). Therefore it is reasonable to look for paleoplacer concentrations downstream of these deposits, in low points of the paleotopography.

In the study area, examples of paleodepressions which have not been sufficiently prospected at depth, include the Moira Valley, immediately west of the Deloro Granite in Madoc and Marmora townships. Further east, the Robertson Lake mylonite zone is a pre-existing shear zone which has given rise to a paleovalley in which enhanced weathering has reconcentrated mineralization from the mylonitized host rocks (Easton 1988).

In the carbonate metasediments, contact aureoles surrounding intrusives bodies produce a corona of skarn rocks predisposed to subaerial weathering at the unconformity. Empirical observation in the Madoc-Marmora area shows that the best development of magnetite-sulphide skarn ore occurs in dolomitic marble. In addition, the dolomitic marbles show a high degree of fracturing. The combined effects of fracture and acid water originating from skarn minerals lead to strong dissolution of these carbonate rocks. Thus, for the prospector, the most favourable site for finding well-developed karst systems will be the contact aureole of plutons in dolomitic marbles, particularly close to sulphide skarn bodies.

Examples of mineralization in karst have been found in the study area, and although the occurrences found are small, one may expect more significant deposits at depth, because the surface karstification which contains the mineralization is only a superficial indicator of possible deeper and more important systems. It is certainly possible that the imbibition and intermediate zones of the karst system are developed at deeper levels, and may contain significant sulphide mineralization. At these deeper levels one may expect narrow subhorizontal veins of sulphides, deposited on a framework of carbonate.

Examples we have discussed so far record reconcentration that took place from host rocks with anomalous Clarke values. Another group of deposits, called locally the post-Ordovician veins, fill fractures that cut both Precambrian and Paleozoic rocks. They have a mineralogy which does not reflect the geochemistry of the basement or the cover host rocks. Ore bearing fluids responsible for this mineralization were channelled, under the Paleozoic cover, through permeable rocks within the unconformity zone. The fluids have come from some distance, and consequently may have a geochemistry quite different from the enclosing rocks. They have generally moved laterally and upward through the host rocks, in contrast to fluids in the karst system which largely circulated downward. Post-Ordovician veins overprint pre-existing structures and mineralization, and they infill open spaces in both basement and cover rocks. The open space framework related to the unconformity is the principal control of mineral deposition, and the local mineralogy developed results from the complex interplay of many geochemical factors. In the study area, empirical observations show that buried karst systems themselves,and fracture intersections of later age, are locations where Eh and ph changes lead to ore deposition.

In principle, paleodepressions with regolithic concentrations, karst systems in contact aureoles in dolomitic marbles, and deep extensions of karst systems, seem to be the best prospecting targets related to unconformities.

SUMMARY

In southeastern Ontario, from the Late Proterozoic to the Early Paleozoic, a paleosurface, subaerially weathered in a tropical to subequatorial environment, developed. On this peneplain, conditions which may have favoured economic mineral concentration were present. Thus, recognition of weathering features at or near unconformity surfaces can be a key factor in locating favourable zones of secondary ore reconcentration related to this unconformity.

In this study we arrived at a better and more complete understanding of the Precambrian - Paleozoic unconformity by synthetizing historical data, and by adding new field observations. Some of the major results of this study are:
(1) that the paleosurface is much more extensive that has been realized and can be easily traced in a broad zone (25 - 30 km) along the south margin of the Paleozoic cover (Map, back pocket) and along the main Paleozoic outcrops, east of the study area; and (2) that there are a variety of mineralization types spatially related to the unconformity.

In the study area, there is a range of features that characterize the unconformity and that allow for the development of predictive models for ore deposition. The most diagnostic field indicators of the unconformity are: (1) intensely weathered surfaces which are inconsistent with post-glacial weathering effects, (2) the presence of hematite both above and below the unconformity. Its distribution is inconsistent with post-glacial weathering effects, and (3) karst features that indicate preferential dissolution of carbonate rocks.
All these features indicate weathering processes occurred under climatic conditions that favoured mineral deposition related to weathering and ground preparation that served to influence latter mineralizaing processes.

From a regional perspective, the unconformity-related mineralization in southeastern Ontario described in this report is the result of the coincidence of two major geological events, both of which contribute to a favourable setting for mineral concentrations. The first of these is the weathering and ground preparation that took place at the subaerial unconformity surface. In southeastern Ontario this occurred in an interval from Late Proterozoic to Middle Ordovician. This episode of erosion is part of an event which undoubtedly was widespread across the North American continental landmass. Locally, along the surface of unconformity, the highest concentrations of economic minerals will be found in paleodepressions wheremechanical and chemical factors have produced weaknesses in the rocks. Such paleodepressions include: karst hollows, collapse gossans over skarn bodies, and eroded fracture zones. In practice, the most highly fractured rocks are the dolomitic marbles. The best development of highly fractured dolomite occurs in contact aureoles around intrusive rocks which also host the principal skarn bodies.

The second major event affecting the shield, in this time interval, was the effect of a global rise of sea level in Middle Ordovician time. Globally the Middle Ordovician marine transgression is associated with mineral concentrations, and in southeastern Ontario, mineralization is related to the extensive interconected permeable system of fractures and karst associated with the unconformity.

It is likely that much of the rest of the Canadian Shield in Ontario has undergone a similar history. It was deeply weathered and then covered by Paleozoic sediments which locally preserved the underlying unconformity-related features. The cover rocks were later removed and the exhumed paleosurface was lowered by glaciation. However, in topographically low areas, the original weathering features may still be preserved, along with any accompanying mineralization.

The principles illustrated by the Precambrian-Paleozoic unconformity in southeastern Ontario can be applied to other regions of Ontario and may serve as exploration tool where an unconformity of similar age exists; for example in the Hudson's Bay Lowlands. In addition, this study will be relevant to workers in southwestern Ontario who study the Precambrian-Paleozoic unconformity in drill holes through the oil-bearing, Paleozoic section.

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APPENDIX

Descriptions of outcrops exhibiting the Precambrian-Paleozoic unconformity in southeastern Ontario. For locations see map in back pocket.

1. ROAD CUT HIGHWAY 7 AT OLD MADOC ROAD

OUTCROP CHARACTERISTICS

Iron enrichment in unconformity zone
Etched paleosurface distinct from smooth glaciated one
Secondary sub-horizontal fracture
Mass wasting below unconformity
Secondary quartz-hematite veins
Soft surface features on paleosurface
Paleosol
Trace fossils

LOCATION

Hasting County, Madoc Township, Concession IV, Lot 2
UTM: 18T - E301200, N4930440

The outcrop is along Highway 7 at the junction with the old Madoc road, 0.5 km west of the intersection with the Hastings County Road 23. There are outcrops north and south of the present Highway 7; and in an old road cut on the south verge of the road.

DESCRIPTION

Dark grey metapelitic rocks striking northwest dip 25-30° NE, are cut by slaty cleavage that strikes northeast and dips 60-70° SE. 1-2 cm elongated magnetite crystals flattened in the slaty cleavage define a rough lineation that plunges 60°NE on the cleavage plane. Westward are dark green metavolcanics with 2-3 cm thick interbeds of jaspery quartz. Late veins of white quartz in the metavolcanics are folded and contorted parallel to the axial planar elements of the slaty cleavage. Quartz rods plunge 70°NE.

Lithified unmetamorphosed red or grey sedimentary detritus unconformably overlies the slates and volcanic rocks (Figure 12). It is horizontally bedded and is 50 cm thick on the upper surface of the outcrop.

Changes seen in the metamorphic rocks below the unconformity intensify upward toward the erosion plane. The slate becomes silvery bleached and thinly laminated parallel to slaty clevage upward in the section. The unconformity zone both above and below is markedly reddened, above by red detritus; below by hematite, coating fractures and net veined quartz veins.

Below the erosion surface, fractures and the slaty cleavage are coated with hematite. Discordant quartz-hematite veins 10-30 cm long and 1-2 cm wide cluster below the unconformity and taper downwards.

The erosion surface has a pronounced microtopography. It is etched up to 5 cm deep along cleavage planes to give a strongly furrowed surface. Above the etched surface a 10 - 20 cm thick zone contains weathered slate debris. In contrast to the weathered appearence of the unconformity surface, glaciated surfaces cut into the slates are smooth and fresh. A rough fracture at 1-2 cm spacings parallels the paleo-erosion surface (Figure 12). Secondary stress-relief sheeting, formed parallel to the paleosurface, allowed down slope creep of sheeted slate blocks. The slaty cleavage is kinked and displaced on this fracture. The upper layers are uniformly displaced downdip on the fracture surfaces. Open spaces developed along the slaty cleavage or along the sub-horizontal fracture have made the rock in this zone more porous. Both porosity and kinking decrease and die out downward within 20 cm of the unconformable ferruginous sandstone.

Three main types of unmetamorphosed detritus lie above the erosion surface. First, there is little-disturbed slate debris, second, a fine-grained red sandstone, and third, a greenish conglomeratic sandstone.

a) In places the outcrop surface of the slate is cut by small paleogrooves 5 cm across which are filled by little-disturbed slate debris and layers of individual magnetite grains. Both the cleavage surfaces of the slate and fracture or kink planes in the slate infill are hematite-coated. A rind, layered parallel to the surface and lying 0.5 cm thick on the erosion plane, is strongly reddened. The valleys, filled 3-4 cm deep with slate detritus, are capped concordantly by a coarser-grained calcareous greenish sandy horizon (third type of unmetamorphosed detritus) with 0.5 cm long pebbles of metavolcanic rocks and angular quartz fragments.

b) The second type of detritus consists of fine, red sandstone enclosing 0.5 - 1 cm chips of silvery slate debris which infills the spaces between the upstanding slate lamellae on the paleosurface. The horizontally bedded sandstone, contains 1 mm quartz grains that are subangular to subrounded in a non-calcareous matrix of 0.1 mm grains. The earliest unmetamorphosed deposits (flat-bedded, fairly mature, non-calcareous red sandstones) include local material in particular magnetite sands, and slate debris, in an allochthonous sand matrix.

The red sandstone which rests discordantly above the weathered slate zone also infills cylindrical tunnels of 3-4 mm diameter that cut into the upper 3 cm of the slate surface. A soil profile of softened slate material that has been bored by worm-like creatures is preserved in paleodepressions. These tunnels, circular to oval in cross-section, descend sub-vertically from the surface for a distance of 1-1.5 cm and branch simply to the horizontal. Their red sandstone infill is concentrically colour-zoned.

Cylindrical tunnels, straight or inverted Y -shaped and subvertical, also cut the red sandstone. They are up to 1 cm long and are more abundant in the first 5 cm of fill immediately above the weathered slate zone. Worm-like organisms lived in sheltered places on surface. In cross section they are circular to oval and 1 - 1.5 mm in diameter. They cut slate chips but do not transect the 1 mm quartz grains. The tunnel interiors are smooth, and striated lengthwise. They have a harder, iron-rich wall of uniformly 0.2 mm sized sand grains. Their regular shape and uniform size distinguish the tunnels from dissolution voids along cleavage planes in the weathered slate.

c) In places a coarse conglomerate with a greenish calcareous sandy cement rests on the bedrock surface above depressions filled with slate debris or the fine red sandstone. The most obvious fragments, which define a horizontal bedding, are white vein quartz 2-3 cm long and 1.5-2 cm thick. There are also cobbles of biotite gneiss, slate blocks, lumps of jaspery quartz and hematite-veined quartz. Of these fragments the biotite gneiss cannot be matched with rocks immediately nearby but the other materials are exposed in the bedrock only 40 metres away. There is little fine fraction, in contrast to the red sandstone beneath. The conglomerate may represent wind-sorted debris or the lag horizons deposited by torrential rains, comparable to modern stony deserts of hamada-type. Burrowing life was absent in the coarse debris horizons.

INTERPRETATION

The pre-Paleozoic unconformity above folded Grenvillian metamorphic rocks is a strongly-weathered paleosurface which has been exhumed from beneath a lithified sedimentary cover. Intense chemical weathering produced colour changes, a strongly-textured surface and increased porosity. Leached iron and silica have been reconcentrated as veins and coatings close to surface. There has been a relative increase of iron in the zone both above and below the erosion plane.

The unconformity is a distinctly red zone. Below, paleo-circulation of groundwater prior to the later sedimentary deposition has leached and reprecipitated iron, staining the Grenvillian bedrock and the paleosols above. Above, iron is concentrated as magnetite heavy sands, as iron-coated sand grains, and as hematite-stained bedrock fragments.

The coarse conglomeratic materials indicate a distinct change of depositional conditions which may be associated with the Middle Ordovician marine transgression.

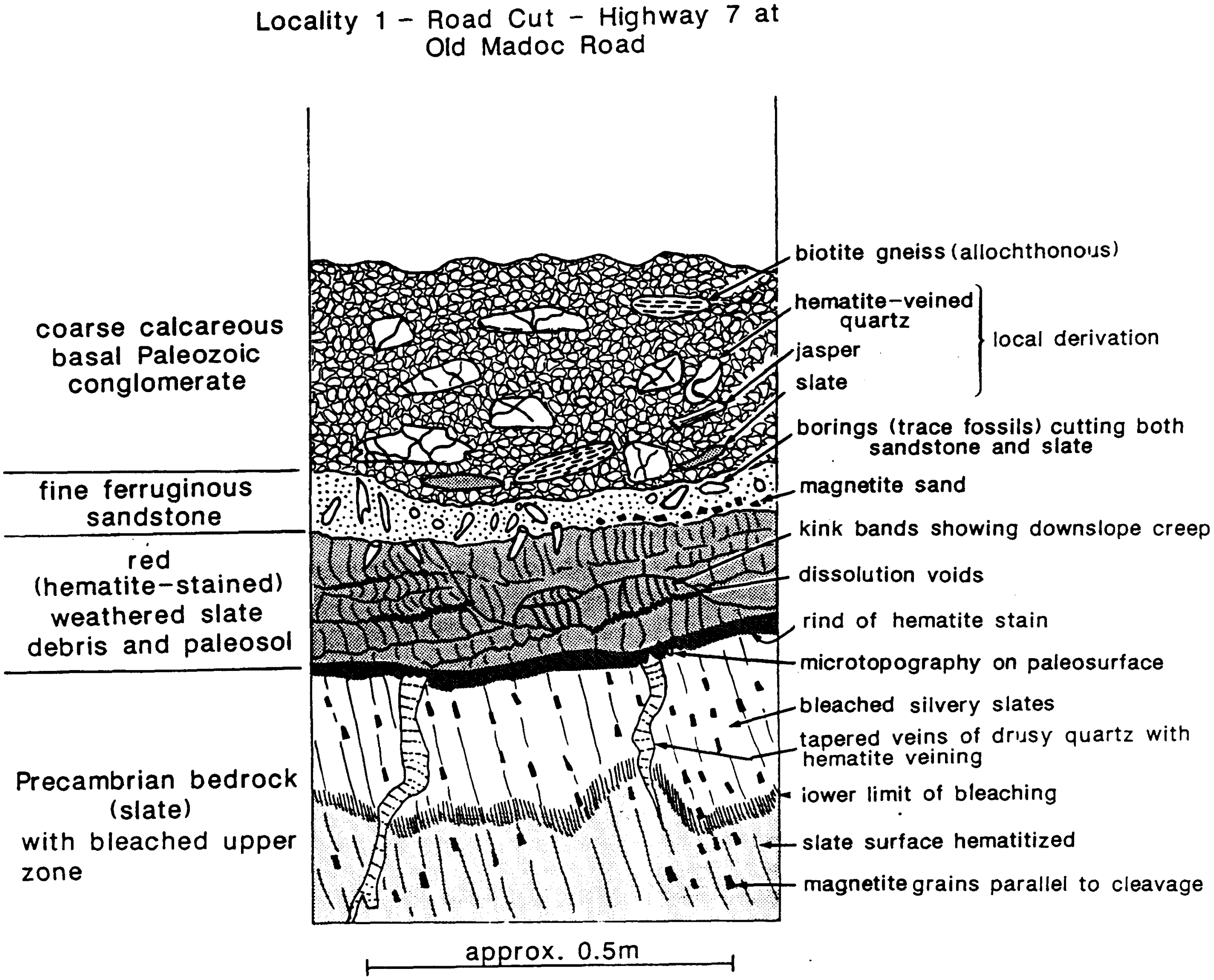


Figure 12: Unconformity features at road cut on Highway 7 at old Madoc Road (locality 1).

2. ROAD CUT HIGHWAY 7 AT HART'S ROAD

OURCROP CHARACTERISTICS

Pinnacled erosion surface

Secondary hematite-calcite veins

Paleosol with hematite stain and siliceous cement

Trace fossils

LOCATION

Hastings County, Madoc Township, Concession VIII, Lot 3

UTM: 18T - E306775, N4932555

The outcrop on the northwest corner of the intersection of the Highway 7 and Concession Road VIII, at Hart's Road shows a 2-3 m vertical face beneath the soil cover.

DESCRIPTION

Dark green-grey calcitic marbles strike 150, dip 80-90° NE. Two to three mm wide bands of flattened tectonic breccia indicate that this rock lies in a tectonic zone which dictates the attitude of the Precambrian bedrock foliation. In a 50 cm wide horizontal zone, 1 - 1.5 m below the glaciated outcrop surface (Figure 13) the foliation planes and quartz veins, which cut and displace the foliation in the marble, are stained purplish red. Ten centimetre wide knots of reticulate quartz show open spaces lined with quartz crystals.

On the outcrop surface a 15 cm wide channel parallel to foliation is filled with a fine green sandstone containing red-brown, marble chips , evident because of their porous weathered appearance and colour. Adjacent to the channel and below the infill, in the uppermost 30-40 cm of the Precambrian bedrock the marble breccia selectively weathers to show rusty voids (0.5 cm long, 3 mm across) oriented parallel to foliation. These are distinct from other 1 mm diameter, spherical to oval tubes which pierce the upper surface of the marble and are trace of boring organisms.

An oriented slab from this location shows the intricate upper surface of the marble beneath the sandstone. Marble pinnacles 1-2 mm across stand 2-3 cm high. Where the marble surface is bare of the green sandstone infill it shows finely etched ribs standing 0.5 mm high and pierced by 1 mm diameter tubes. Horizontal layering of the sandstone discordantly abuts the marble and are depressed toward the channel centre. The infill comprises a brown-green sandstone (grains 0.1-0.2 mm across) diffusely colour-banded, containing horizontally-lying, red-stained chips of marble. This sedimentary banding has been partly overprinted with a red jaspery silica cement. In the first 20 cm of the sandstone above the unconformable contact with the Precambrian marble, 1-1.5 mm diameter tubes, up to 0.5 cm long occur and are lined with a fine silica coating on their inner walls. These are probably fossilized worm tubes.

INTERPRETATION:

A karst hollow 30-40 cm deep in calcitic marbles is filled with younger sandstone. Weathering has selectively attacked a tectonized zone increasing pore space and causing reddening by redistributed iron immediately below the paleo-erosion surface. The paleosurface shows a delicate ribbed 0.5 mm microrelief, and where protected by later deposits, a jagged erosional topography 2-3 cm high. A paleosol of finely bedded sand, incorporating local marble chip debris, fills the karst channel. Boring or burrowing creatures have attacked both the erosionally-etched Precambrian bedrock surface and the sandy infill in the first 10-20 cm above the unconformity. Both boring organisms (which attack indurated surfaces) and burrowing organisms (which invade soft substrates) were well developed in Lower Paleozoic time (Kobluk et al. 1978, Frey and Pemberton 1984, Warme and McHuron 1978). Boring and burrow traces are reported from the Lower Cambrian in coastal Labrador, representing braided fluvial environments or rocky shorelines where the substrate may consist of material as hard as igneous or metamorphic rocks. At the Hart's road locality the trace fossils marks indicate either that the earliest sediments were lithified and that both they and the Precambrian substrate were bored; or that both borers and burrowers were present. Circulating groundwater subsequently redistributed iron and silica to stain and cement both bedrock and the karst infill.

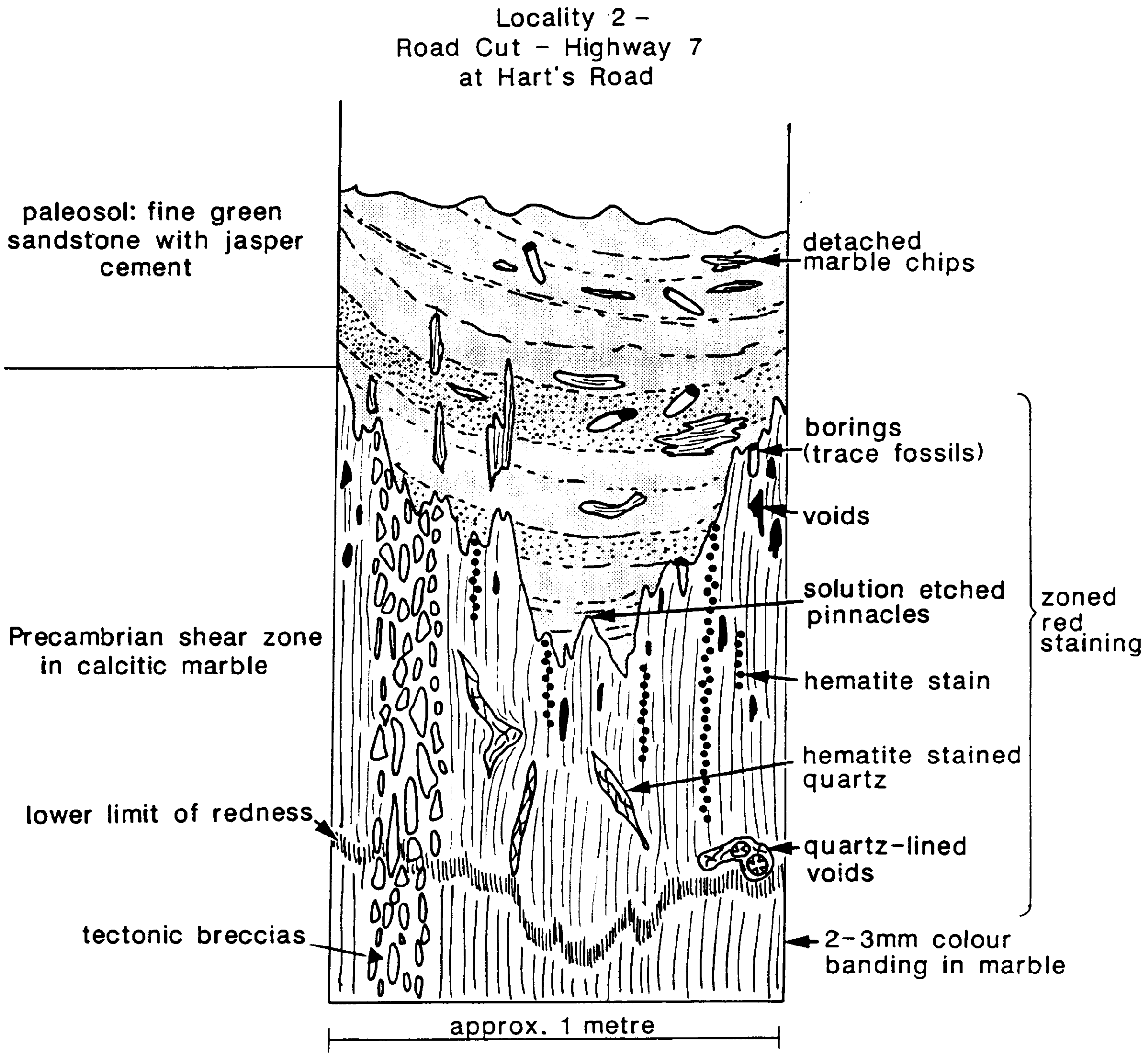


Figure 13: Unconformity features at road cut on Highway 7 at Hart's Road (locality 2).

3. CANADA TALC QUARRY

OUTCROP CHARACTERISTICS

Karst structures

Lag gravel of resistent minerals

Boulder ridge of Paleozoic age

Trace fossils

Redistribution of calcium, iron, silica, and copper

Epigenetic karst mineralization

Epiclastic mineralization

LOCATION

Hastings County, Huntingdon Township, Concession XIV, Lot 15

UTM: 18T - E305250, N4930400

The Canada Talc mining operation is situated at the southeast border of the town of Madoc.

DESCRIPTION

Geological setting:

Talc was discovered at the turn of century and has been extracted since. The talc occurs in Precambrian dolomitic marble, intruded by a granitic body. It is considered to be metasomatic in origin, formed where hydrothermal solutions from the granitic body have ascended through fractures and faults to produce the various mineralization types hosted by the metasedimentary carbonate rocks. In addition to talc, several small veins of sulphides up to 7 cm wide cut the metasediments.

The Precambrian bedrock comprises impure calc-silicate skarn rocks that strike northeast and dip vertically. In the skarn zone, foliated white dolomitic marble is interbanded with more mafic horizons 2-3 m wide. Talc, magnetite, tremolite, amber mica, and dark red-brown tourmaline are skarn minerals produced by alteration· adjacent to the granite intrusion. Interbanded with the impure marbles are tabular bodies of finely laminated white quartzite which are oriented parallel to the marble foliation (Figure 14). These quartz rich bodies each 15 to 20 m in length, and 10 to 20 cm thick have been described by Bourque (1982) and interpreted as relict algal-laminite stromatolites which have been silicified and recrystallized. Commonly, these bodies shows millimetre-thick laminations as an internal structure parallel to their extension, and occasionally a match-like rodding of mineral grains normal to this banding. The lamination is interpreted to be growth lamellae of the stromatolite colony; the rodding is recrystallization which pseudomorphs other internal organic structures. The stromatolites have been folded and up-ended so that originally-horizontal growth laminae are now vertical.

In the northeast pit of the mining operation a small outlier of Paleozoic rocks rests on the Precambrian metasediments. The Precambrian erosional topography in the pit shows a basin shape 200-300 m wide. Reddish-brown Middle Ordovician pebbly shale, sandstone and limestone cover the Precambrian marbles. In the pit, mine benches display 15 m vertical cross sections of the marble beneath the Paleozoic cover (Figure 14).

At the bottom of the topographic depression, the marble is locally dissolved to at least six metres deep. Karst features such as sink holes, dissolution cavities, and bedding joints enlarged by dissolution are exposed. Oxide, carbonate, and sulphide mineralization occurs at the paleosurface as well as in the karst features beneath.

At the unconformity, green or strongly reddened, lithified but unmetamorphosed, sandstone rests on the broad horizontal erosion surface which truncates the marbles (Figure 14). Residual debris resting on the surface includes lithified, iron-cemented lag gravels of 2-3 cm long tourmaline prisms, and a horizon of disoriented boulders (up to 0.75 m across) of pink, finely laminated stromatolitic quartzite. Both are derived from the local bedrock.

On the erosion surface, fracture planes control the distibution of dissolution features. Karst features include smooth hollows (10 cm across, 20 cm deep), channels (amplitude 0.5 m, 30 cm deep) and vertical chasms (3-4 cm wide, 10-20 cm deep). The east benches of the pit show that locally karst hollows extend 5-6 m below surface, and contain greenish basal Paleozoic infill.

In the less soluble calc-silicate rocks such, as the tourmaline skarn, dissolution at surface appears as joints widened to 1-2 cm or as shallow pitting. Where folded stromatolite rocks are cut by the erosion surface, the laminae are etched 2-3 cm deep to give furrows spaced 1-2 cm apart (Figure 14).

There is concentration of ferric iron in the unconformity zone. The surface of the marbles is stained and coated with films of iron oxides. A wide-spaced horizontal fracture at 1-2 m intervals shows infiltration of staining and seepage of the red stain down the foliation lamellae.

On the northeast corner of the first bench in the bedrock, modern weathering of the sulphides, which line karst cavities, produces an orange brown limonitic stain on the dolomite face. This is different from the red stain related to the paleoweathering.

Pods of magnetite skarn (20-30 cm thick and 3-4 m long) have a 2-3 cm thick crust of softer hematite above them at the paleosurface. Stromatolite blocks in places have a 1-2 cm crust of iron cemented, siliceous, partly calcareous sandstone stuck to their upper surfaces (Figure 14). Red staining has seeped down the stromatalite laminae for several centimetres. The lag gravels immediately overlying the erosion surface are cemented with ferric iron oxide.

The oldest material capping the unconformity surface closely reflects the bedrock beneath. In places it is a conglomerate of sub-rounded, 1 cm sized fragments of quartz, magnetite, and hematite in a green, sandy (grains 1-2 cm diameter) partly calcareous matrix. Elsewhere the basal unmetamorphosed rock is a purplish sandstone forming a ferricrust with angular 1 mm sized chips of vein quartz in a horizon 5 cm thick. The ferricrust is the oldest material on the paleo-erosion surface and is overlain by red-purple or green siltstone and pebbly calcareous shale, and finally by grey-green limestone. Colour variation in the calcareous sandstone are common. For example, the tourmaline skarn is overlain by horizontally bedded, fine-grained calcareous sandstone (grains 1-1.5 mm in diameter) which infills erosional depressions cut parallel to foliation in the skarn rocks. For a distance of 1-2 cm from the erosion surface the sandy infill is green. Above and further away from the erosion plane, the sandstone is reddened although the fabric of the sandstone is continuous across the colour change.

A train of boulders of silicified stromatolitic marble (each up to 0.75 m across) rests about 2 m deep on the erosion surface (Figure 14) and is embedded in unmetamorphosed sandy siltstone and shale. Dissolution voids in the boulder are controlled by fracture and the stromatolite laminae. The voids are lined with calcite crystals and red staining and are randomly positioned relative to the erosion surface. Some boulders are upside down and show the brown sandy ferricrust on their present lower surfaces. The silicified stromatolite is porous and reticulate immediately "above" this iron crust, but "upward" becomes more dense, paler and more siliceous. The present "upper" part of the boulder consists of clean pink silica.

Greenish purple silts and fine calcareous sands which fill spaces between boulders are pierced in all directions by simple tube-like voids (2-3 mm across and up to 1.5 cm long) which are fossil traces of burrowing organisms. They are numerous between the boulders and also close to the erosional surface where upstanding ribs of dolomite form a jagged microtopography 10 cm high. A vertical polished slab of the erosion interface shows vertical dolomite ribs 10 cm high and 2 - 3 cm apart, infilled with red silts. Narrow cylindrical chanels (2 - 3 mm in diameter, 3 - 4 cm long) filled with pale cream sandstone pierce the red sandy ferricrust and the upper surface of the Precambrian marble. Above the boulder horizon 3-5 mm wide vertical cylindrical structures which descend 2-3 cm from particular sedimentary layers in the Paleozoic green silt are infilled with red silt. The distribution of the trace fossils may represent their response to more favourable sheltered environments during the Paleozoic deposition.

Setting of mineralization

As mentioned, there is pervasive impregnation of red iron oxide in the uppermost zone of the Precambrian metasediments, and patches of thin crusty red hematitic ferricrust occur at the paleosurface (Figure 15).

Mineralization in the karst occurs in different ways. Along the walls of the dissolution cavities occur mineralized layers, consisting mostly of carbonate (calcite, dolomite, ankerite, azurite, malachite), and sulphides (pyrite, chalcopyrite). Although erythrite was found, no sulphides of cobalt are visible. The thickness of the layers ranges from a few millimetres to 10 - 15 cm. In open spaces, euhedral crystals of carbonates cover the uppermost layers of the mineralization (Figure 15). Some of the sink holes are filled with epiclastic Paleozoic sediments. Green to reddish coarse immature sandstone is exposed in the karst. The cement of the sandstone is mostly calcareous, but in some places a syngenetic chalcopyrite cement occurs, (Figure 15). Analysis of this sandstone shows copper contents of up to 1.4% (Geoscience Laboratories, Ontario Geological Survey). The extent of the copper-rich sandstone is very limited.

INTERPRETATION

Grenville dolomitic marble and skarn, together with lenses of silicified stromatolites, underwent subaerial erosion and weathering in the Late Proterozoic-Middle Ordovician. Karstic dissolution has formed depressions up to 6 m deep below surface.

Silica and calcium carbonate were partially removed. This increased porosity in the rocks up to tens of metres below surface. Gossans formed on iron skarns. The surface was patchily covered by lag residues (hematite fragments, magnetite grains and fragments, and eroded remnants of silicified stromatolitic lenses). Iron stained the exposed surfaces and cemented the fine quartz sands infilling hollows, forming a hematite-rich ferricrust.

Later, during the Middle Ordovician marine transgression, weathered stromatolite blocks were deposited in a boulder train on the erosion surface. Protected areas between the boulders became a habitat for boring organisms. Hematite gossan and the underlying skarn magnetite were eroded and incorporated into the Middle Ordovician basal classic sediments. The later calcareous sandstones are coarser and less mature than the sand incorporated in the ferricrust on the paleosurface. They have been patchily reddened, and the same reddening emphasizes vertical burrows higher in the carbonate portion of the Paleozoic succession. Fossil traces show that both borers and burrowers were present at the onset of Paleozoic sedimentation. The borers attacked both the Precambrian bedrock (dolomite) and a ferricrust above it that was presumably also an indurated surface. The borers were especially plentiful where boulder piles or rocky high spots provided a suitable environment.

Burrowers, which appear higher in the sequence, but within a metre of the unconformity, are restricted to the fine calcareous sands of the later deposition. This presumably also reflects their adjustment to a particular preferred habitat.

The metasomatic skarn deposits at the Canada Talc open pit have been subjected to subaerial weathering during Late Proterozoic to Early Paleozoic times. In this weathering environment, reaction of sulphides with groundwater caused the formation of aggressive acidic solutions. These in turn induced dissolution and the formation of karst. Silica, copper and calcium were leached and reprecipitated in the open spaces created. Copper and calcium were remobilized again during the Paleozoic, forming syngenetic sulphides and carbonates in the basal Paleozoic sandstones in the karst cavities. Supergene reconcentration of iron was less important because of the low content of iron in the Precambrian protolith and skarn deposit.

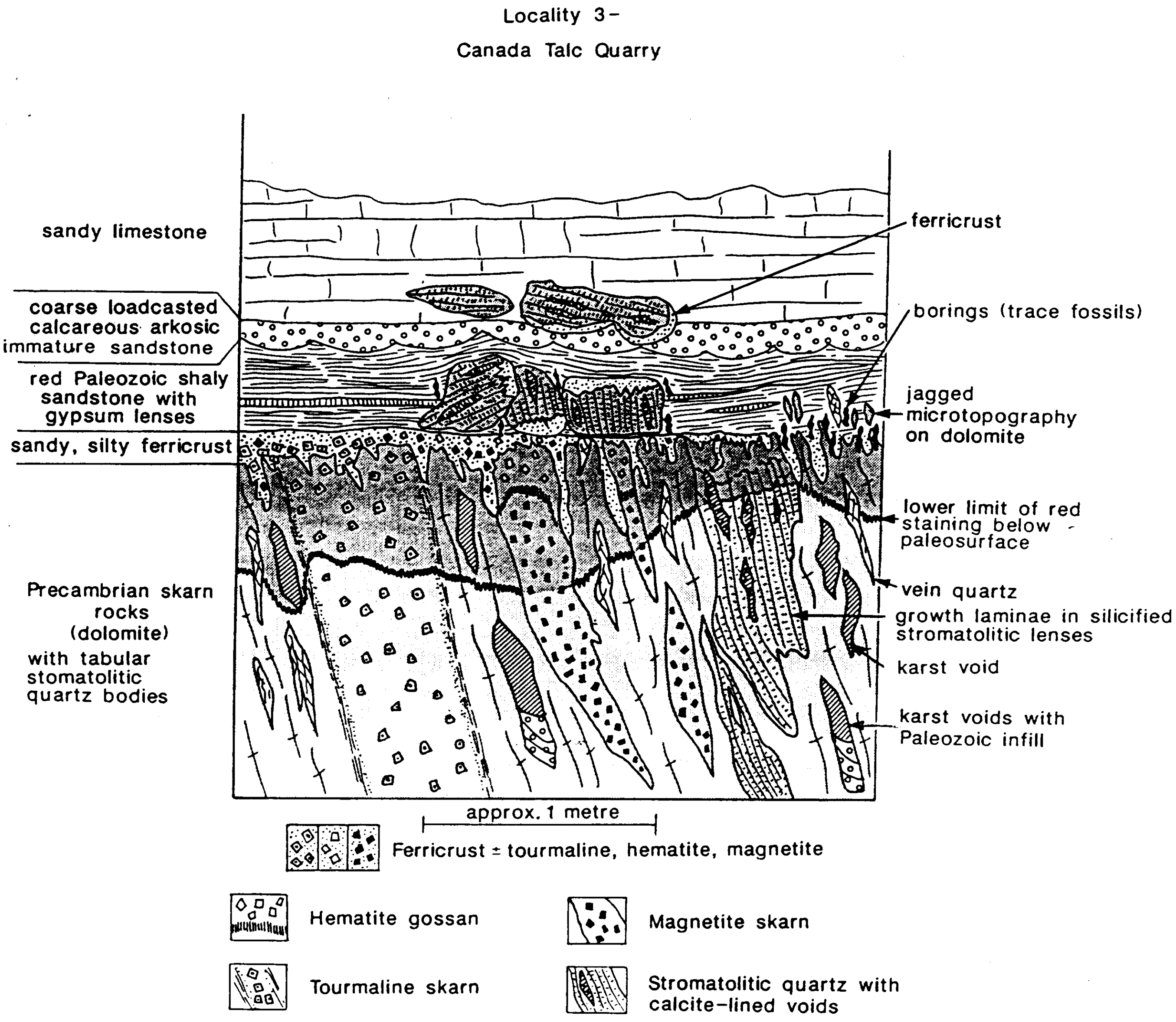
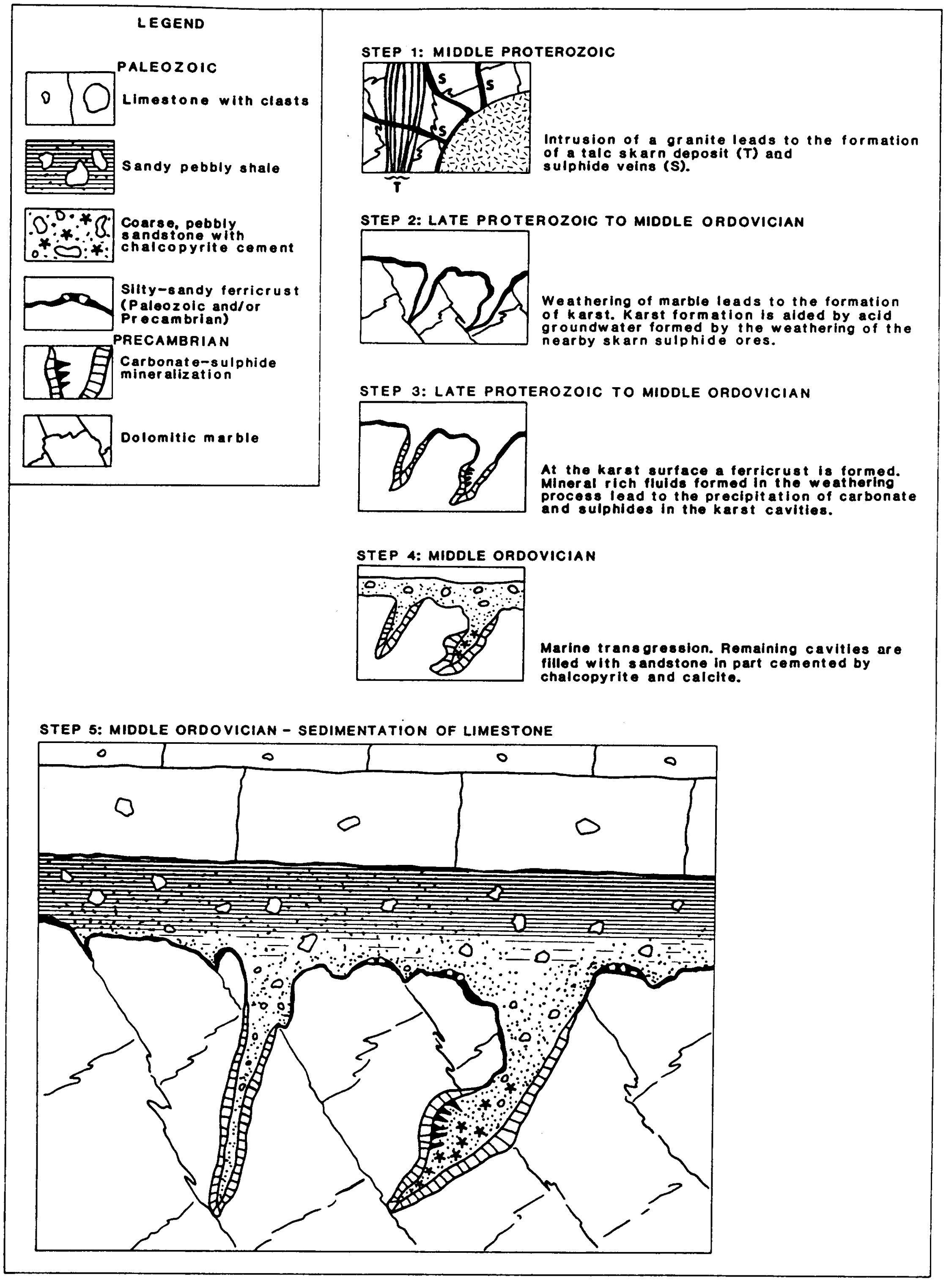


Figure 14: Unconformity features exposed at the Canada Talc Quarry, Madoc (locality 3)



STEP 1: MIDDLE PROTEROZOIC

Intrusion of a granite leads to the formation of a talc skarn deposit (T) and sulphide veins (S).

STEP 2: LATE PROTEROZOIC TO MIDDLE ORDOVICIAN

Weathering of marble leads to the formation of karst. Karst formation is aided by acid groundwater formed by the weathering of the nearby skarn sulphide ores.

STEP 3: LATE PROTEROZOIC TO MIDDLE ORDOVICIAN

At the karst surface a ferricrust is formed. Mineral rich fluids formed in the weathering process lead to the precipitation of carbonate and sulphides in the karst cavities.

STEP 4: MIDDLE ORDOVICIAN

Marine transgression. Remaining cavities are filled with sandstone in part cemented by chalcopyrite and calcite.

STEP 5: MIDDLE ORDOVICIAN - SEDIMENTATION OF LIMESTONE

Figure 15: Formation of mineralization in karst at the unconformity at the Canada Talc Quarry, Madoc (locality 3)

4. HIGHWAY 62 AT RIMINGTON ROAD

OUTCROP CHARACTERISTICS

Permeable fabric in Precambrian bedrock
Pinnacled karst erosion forms
Secondary fracture fabric
Terra rossa
Caliche

LOCATION

Hastings County, Madoc Township, Concession V, Lot 18

UTM:18T - E299655, N4940670

Outcrops occur on both sides of Highway 62, 150 m north of Rimington Road.

DESCRIPTION

The outcrop consists of buff-cream, laminated dolomitic marble with conchoidal fracture that strike 030°, and dip 80°W. Bands and pods (2.5 cm wide, 10-20 cm long) of white or clear quartz with fine longitudinal laminations and a match stick-like cross fabric of grains normal to the laminae occur in the dolomite. There are interbeds (0.50-1 m thick) of blue, well laminated calcite marble. About 120 m north of the road intersection an anticlinal closure plunges 60/58°. Strong rodding parallels the axis of the anticline.

Vertical fractures spaced 10-50 cm apart strike 010°. Horizontal fractures are spaced 10 cm apart at the base of the 2.5 m high outcrop, and 2.5 cm apart near the top of the exposure. The east side of the road has a rubbly appearance and exhibits fine sub-horizontal calcite laminae (thickness 2-5 mm) that separate the platy dolomite slabs (0.5 cm - 1 cm thick). Some fracture planes are red-stained, one of these is vertical and strikes 056°. The weathered rock surface shows hair-line fractures, deepened to 1-2 mm relief, that cut across the surface. This etch pattern is darkened by a modern algal film. Glaciated surfaces do not show a dark film.

At roadlevel at the southwest corner of the intersection of Rimington Road with Highway 62, fine-grained, red and green sandy silts with small chips of clear or milky quartz and yellow dolomite, infill vertical crevices in the dolomite (Figure 16). These crevices are 5 cm deep and at 10 cm spacing. On the western outcrop face a widened joint leads to a 20 cm wide channel 1.5 m below outcrop surface, which extends 2 m further down, to road level. This channel is filled with a fine-grained, white mature sandstone (grains rounded, 0.2-0.5 mm in diameter) with pebbly quartz grains and soft, greenish chloritic pellets. Bedding in the sandstone is discordant to both channel walls in the vertical face (Figure 16). The sandstone is colour-mottled, orange,-pale green, dull red and unevenly cemented by silica and overprinted with a later coarse calcite cement.

A sample of a sandstone-filled cavity in the Precambrian dolomite cut both vertically and horizontally, normal to the channel walls shows that the cavity parallels the metamorphic foliation of the dolomite. Narrow 2-5 cm high dolomite pinnacles (Figure 16), infilled by the sandstone, show rusty alteration on outer surfaces. The dolomite is porous around the cavity. Remnant dolomite chips enclosed in the sandstone are reddened and porous.

The lithified sandstone infill strikes 130° dips 65° NE and bedding curves upward against the cavity walls in all directions. Bedding is emphasized by chloritic pellets; by quartz pebbles up to 0.5 cm across; by voids; and by patches of later, coarse-grained calcite cement.

INTERPRETATION

A 2 to 3 m paleotopography is preserved in the Precambrian dolomite. Karst features developed along bedrock fractures resulted in a pinnacled paleosurface. Other karst features are; etched paleosurfaces, cavities along joints and increased porosity in the dolomite. Removal of calcium carbonate has left orange-stained coatings and porous reddened residues (terra rossa) on the remnant dolomite. A strong secondary subhorizontal sheeting parallel to the paleosurface, and precipitation of laminated secondary calcite, indicate incipient caliche development.

White, fine-grained, mature, possibly eolian, sand sifted into karst cavities. Groundwater circulation altered mafic fragments to chlorite and partly recemented the sand with calcite. A later depositional event, probably related to the Middle Ordovician marine transgression, swept up local fragments of laminated quartz from the dolomite and infilled cavities with Paleozoic red or green sandy silt.

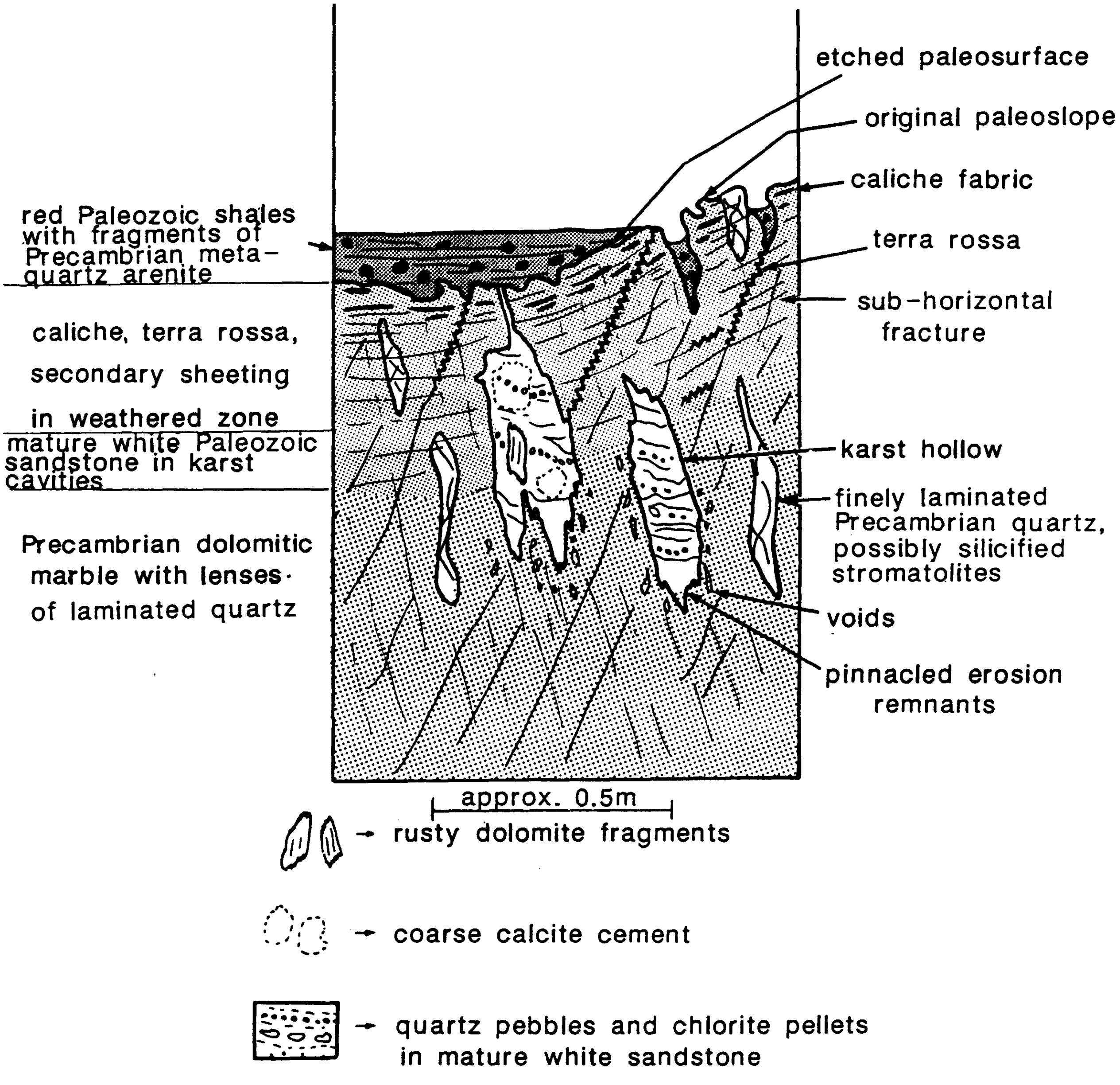


Figure 16: Unconformity features at Highway 62 and Rimington Road (locality 4).

5. THE SILO QUARRY AT BARKER ROAD

OUTCROP CHARACTERISTICS

Microtopography on paleosurface
Increased Porosity
Broad paleotopographic features visible
Redistribution of iron, silica, calcium carbonate

LOCATION

Hastings County, Madoc Township, Concession VI, Lot 22

UTM: 18T - E300250, N4942950

The outcrop is in an old quarry of Stoklosar Marble Quarries company, approximately 1 km east of Highway 62 on Barker Road.

DESCRIPTION

An old, partly water-filled, marble quarry exposes a vertical north-south scarp of dolomite with a strong lineation plunging 45°N on vertical foliation that strikes 330°. Horizons of white laminated quartz, 10-20 cm thick and 0.5-2 m long, parallel the foliation in the dolomite. The unconformity between Precambrian dolomite and horizontally bedded Paleozoic pebbly quartz sandstone with a greenish calcareous cement is preserved as an erosional remnant west of the dolomite scarp (Figure 17). The vertical dolomite scarp clearly represents a pre-Paleozoic fault which has influenced deposition.

Above the erosion plane, blocks of yellow dolomite rest against the cliff to the east. The largest blocks lie closest to the dolomite wall and decrease in size away from it. A pre-Paleozoic wedge of bouldery scree is preserved below the dolomite cliff face and is enclosed by Paleozoic, green, calcareous, immature pebbly sandstone of local derivation. One- to two-centimetre rectangular lumps of quartz in the basal sandstone can be matched with the rocks immediately below. The overlying rocks rest on a reddened, strongly etched erosion surface that shows 3 cm deep solution furrows. Below the unconformity (Figure 17), 20 cm open cavities lined with spar calcite and voids 0.5-3 cm long parallel to foliation are present. Iron oxide and jasper cements redden the foliation planes, and irregular fractures parallel to the unconformity. White quartz pods are stained red on fractures.

INTERPRETATION

Subaerial weathering on the erosion plane prior to the Middle Ordovician marine advance produced a deeply etched, porous karst horizon. Calcium carbonate has been removed. Iron silica and calcium carbonate have been recirculated by a groundwater system. A scree slope to the west of a ridge of Precambrian dolomite indicates 20-30 m of original paleorelief.

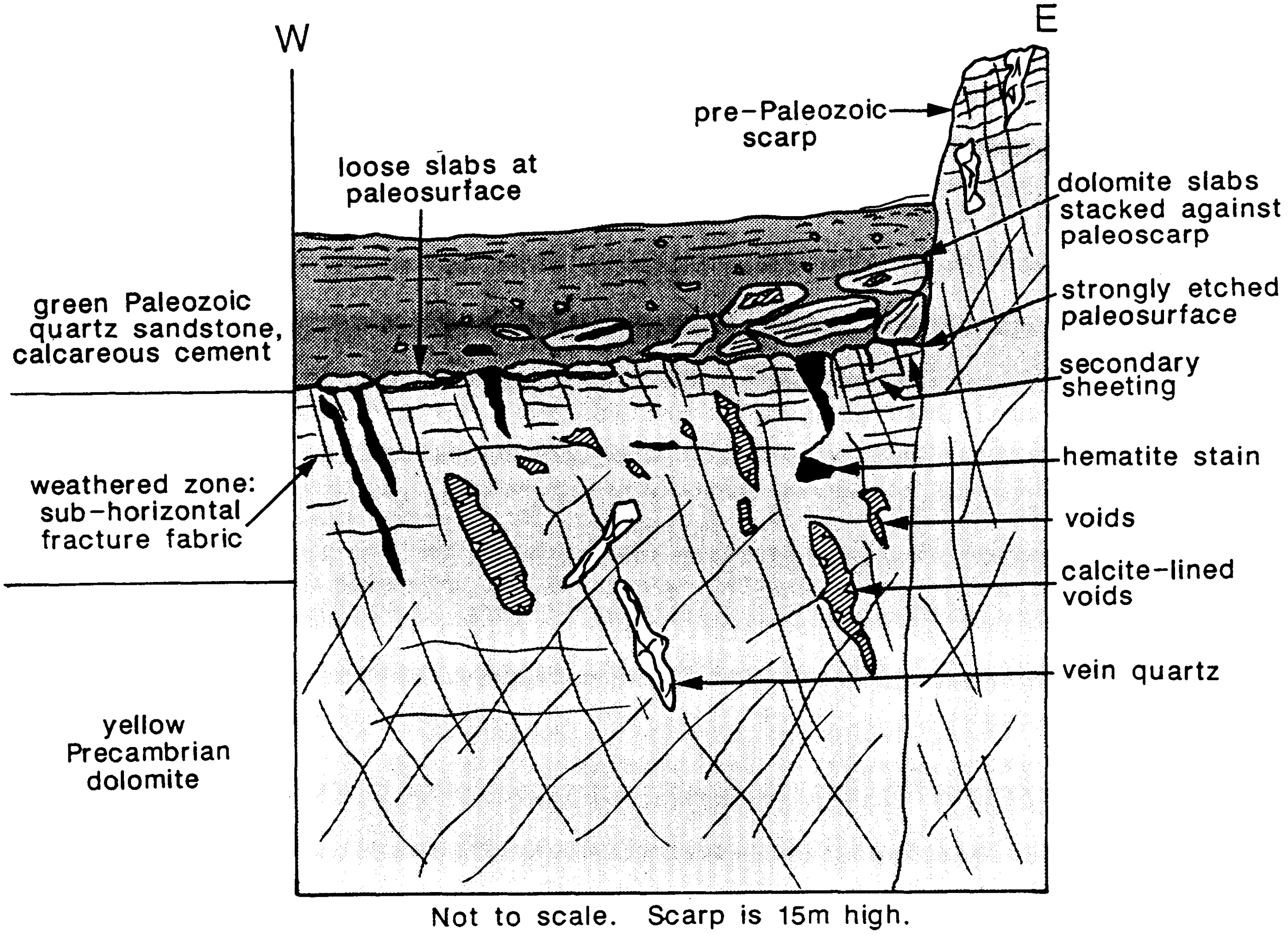


Figure 17: Paleorelief, paleokarst and Paleozoic sedimentation at the silo quarry at Barker Road (locality 5).

6. MARMORATON IRON MINE

OUTCROP CHARACTERISTICS

Spheroidal weathering of metabasite

Net veining with hematite below unconformity

Paleosol profile

Lag horizons with Paleozoic ventifacts

Pre-Paleozoic regolith

LOCATION

Hasting County, Marmora Township, Concession V, Lot 5

UTM: 18T - E288735, N4928245

The large open pit lies southeast of Marmora, south of Highway 7 and east of County Road 14. The Marmora 5th line turns south off Highway 7 east of Marmora and leads to the open pit.

DESCRIPTION

The Marmoraton iron orebody consisted of a tabular body of magnetite-bearing skarn striking roughly N-S and dipping steeply west at the contact between Grenville marbles and a syenite-diorite intrusive complex. The orebody was unconformably overlain by about 50 m of flat-lying Ordovician limestone which was stripped away prior to mining. The only exposures of the orebody and host rocks are in the open pit.

Marble, skarn (including ore), syenite, diorite, siliceous metasediments, gabbroic dikes, and flat-lying Ordovician limestone are exposed in the pit. The skarn and ore zone occurs along the contact between syenite and marble and is inclined steeply to the west. Crude layering in the skarn rock and ore is generally conformable with layering in the marbles. The orebody consisted of a lens of iron ore ranging from 15-

20m thick, about 610 m long, and extending down-dip for at least 220m. Diorite occurs as small poorly exposed patches in the western part of the pit, intrusive into siliceous metasediments.

The unconformity between Precambrian rocks and overlying Paleozoic strata is well exposed along the walls of the pit, and undulations in the pre-Paleozoic surface can be seen on the north and west walls (Figure 18). Paleozoic strata include the Shadow Lake Formation and the Gull River Formation (late Middle Ordovician). The Shadow Lake Formation consists of red silty and sandy shale with a basal conglomerate resting directly on the Precambrian. It is overlain by about 50 m of grey lithographic limestone with dolomitic interbeds of the Gull River Formation. The contact between the formations is half-way up the second bench.

The hummocky unconformity surface can be seen on the south and west faces of the open pit. The exhumed paleosurface is exposed on the bench floor. It is net veined with 1-2 mm ribbons of hematite in cracks at the surface. Coarser hematite-calcite veins or pods also occur. In vertical section, the siliceous skarn bedrock shows a bleaching and a secondary foliation parallel to the paleosurface which extends but decreases in intensity 20-25 cm downward. The upper 5 cm are loose, friable and consist of in-situ fragments of bedrock (Figure 18). This is incorporated as a paleosol horizon which predates the Paleozoic rocks.

For 2 m below the surface, spheroidal weathering of the diorite has formed rounded blocks with a loose iron-stained rind. Fracture planes are coated with hematite. Immediately above the diorite, in local depressions on the flanks of the diorite surface (Figure 18), lies dark red, layered sandstone containing 1-2 cm lumps of red-coated diorite. The layering is 10 cm thick. At the crest of the small dome 0.5-1 cm sized chips of epidote-andradite skarn, magnetite, and maghemite occur in a dark green sandstone (grains 0.25 mm across) of quartz and magnetite grains. These red and green largely non-calcareous sandstones with abundant hematite and magnetite are interpreted as a pre-Paleozoic regolith representing the weathered detritus from subaerial erosion of the Precambrian skarn magnetite body and its hematite gossan. They rest unconformably above the Precambrian bedrock, and disconformably beneath the Paleozoic calcareous shaley sandstone. The Paleozoic sedimentary sequence, which continues above the regolith, shows the same red-green colouration but the rocks are more shaley, and the cement is calcareous.

On the west face of the open pit, a small dome of Precambrian diorite is exposed which is flanked on either side by blocks of spheroidally-weathered diorite and blocks of vein quartz up to 0.5 m across (Figure 18). All these blocks are enclosed in red or green shale, which rest unconformably above the diorite, and are truncated against it. These deposits are red or green gritty shale with 1-2 cm rectangular quartz fragments. The outer surface of the quartz fragments is dull in lustre (in contrast to the shiny surface of a freshly broken vein quartz of the skarn rock), and show shallow surface pits 0.5-1 mm across. At one horizon, 5.5 m above the erosion plane, 2 cm sized quartz pebbles with a flat base and a low pyramidal profile occur. These appear to be ventifacts (wind-shaped pebbles) (Figure 18). They are confined to one horizon and are oriented with the flat base downward. The etching of the pebble surfaces seems to be a later effect, perhaps due to interaction of the calcareous cement of the enclosing sandstone with the quartz pebbles. Similar textures have been reported in several other localities (Krinsley and Doornkamps 1973). The shape and distribution of these ventifacts suggest that they are lag deposits from which finer material has been removed, perhaps by wind action.

Other climatic evidence is given by the presence of evaporites immediately above the ventifact horizon. Here a 0.5-1 cm thick horizon of fibrous gypsum is preserved. Desiccation textures are revealed by shale flakes which curve upwards. Higher in the Paleozoic section, below the main sequence of grey limestone, 10-20 cm thick beds of green sandstone with pebbly layers show load casting. The red shale below are squeezed upward along fractures in the sandstone, giving facing directions.

INTERPRETATION

The original slopes and paleorelief are preserved on the unconformity surface. The surface rock, notably the diorite, was pervasively weathered subaerially along joint planes to give an onion-skin appearance. The paleoweathering can be clearly distinguished from current weathering by its intensity and the hematite veining which pervades the weathering rinds. Exposed magnetite ore in the Precambrian basement rocks was hematized forming a gossan. Hematite staining and net veining of the rocks occurred close to the paleosurface. Bleached friable paleosols were formed immediately beneath the erosion surface.

The earliest overlying deposits are local in origin. They include skarn fragments, magnetite sands and hematized material from the gossan. These appear to predate the Shadow Lake Formation proper (D. Williams, geologist, Ministry of Northern Development and Mines, Tweed Office, oral communication).

The sedimentology suggests that the earliest Paleozoic at this locality, the Shadow Lake Formation, was formed under tropical conditions which produced evaporites and dessication textures. Dessication textures are represented by dried crusts of silty material which were separated into fragments and are then enclosed in silt, probably in mud-flats. A tropical environment is consistent with the work of others (Noor and Kobluk 1986; Steele-Petrovich 1986). Noor et al. (1986) demonstrated the physiographic complexity of this Ordovician shoreline, which has given rise to great variation in thickness and type of deposited sediments. They also show that there is an intimate relationship of bedrock and the overlying sediments, and that a thick regolith on the Precambrian was reworked into the Shadow Lake Formation. Noor and Kobluk (1986), Steele-Petrovich (1986) and Selleck (1984) infer that the first Paleozoic deposits formed on intertidal flats, mudbanks, logoons and rocky shorelines in a shallow transgressive tropical sea, which lay in the path of storms and hurricanes (Dalrymple et al. 1985, Marsaglia and Klein 1983).

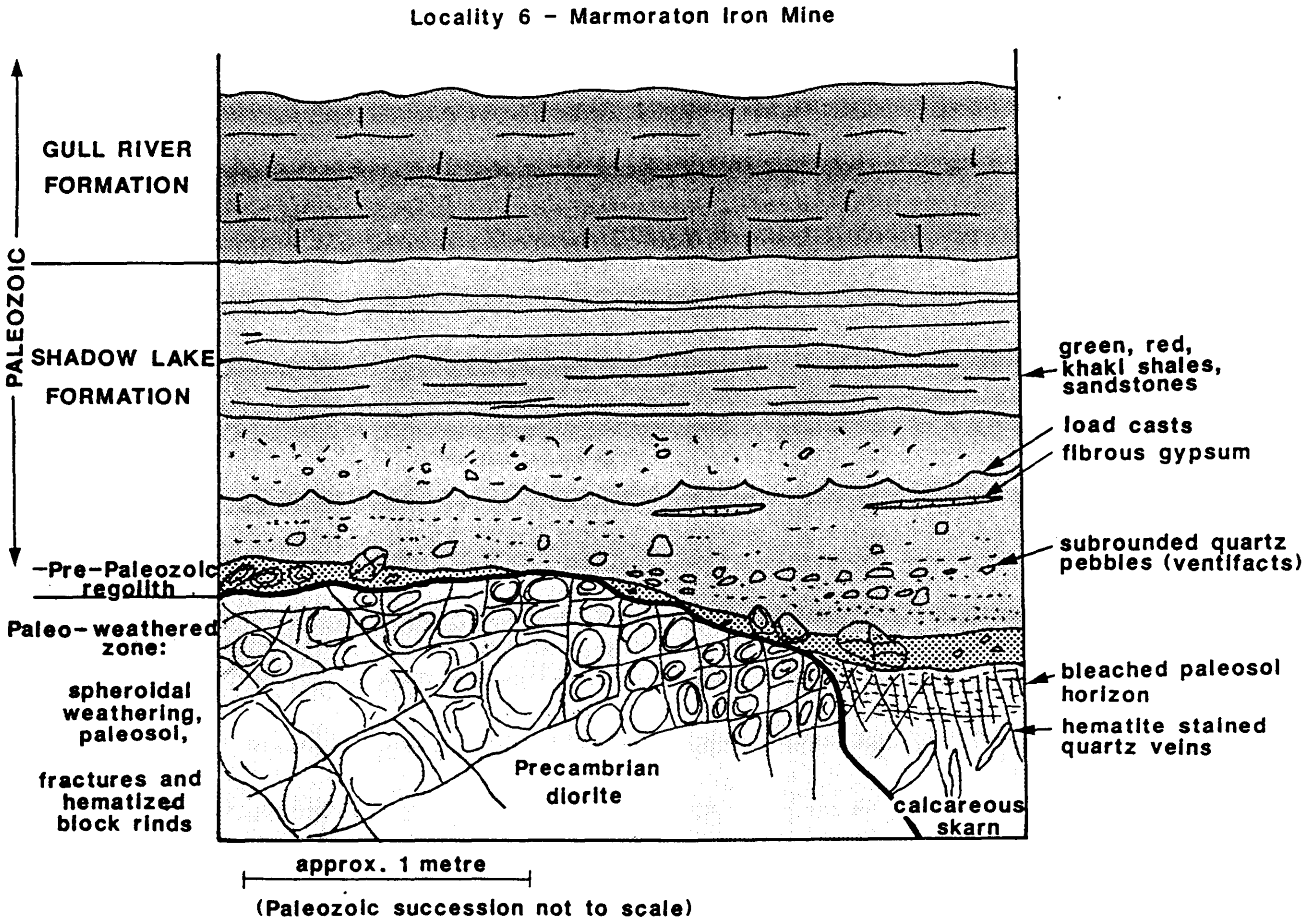


Figure 18: Subaerial erosion features at the Precambrian-Paleozoic unconformity at the Marmoraton iron mine (locality 6).

7. PUBLIC SCHOOL ROAD AT CONCESSION VII ROAD

OUTCROP CHARACTERISTICS

Horizontal sheeting parallel to paleosurface

Karst structure

LOCATION

Hasting County, Madoc Township, Concession 6, Lot 12

UTM: 18T - E301900, N4937090

Outcrops showing the unconformity occur on north and south side of Public School Road in Madoc Township east of Highway 62, about 5 km north of Highway 7.

DESCRIPTION

Blue, fine-grained Precambrian calcitic marble, strongly folded on vertical axial planes, shows rough subhorizontal fracture sheeting at 5-10 cm spacing (Figure 19). The sheeting, forming slabs, cuts across the metamorphic fabric and becomes more abundant and more evident upward toward the erosion surface. The slabs are 5-10 cm long and 1-2 cm thick and become progressively further detached from the bedrock above the erosion plane and are enclosed in pebbly Paleozoic sandstone. A polished slab cut normal to the strike of the metamorphic fabric and normal to the erosion surface shows a scallopped interface between marble and sandstone. A 0.5 cm thin rind of yellow weathering lines shallow karstic depressions, 4-5 cm across, in which the pebbly sandstone rests. The marble below is stained orange by iron oxide for up to 30 cm depth. Small karst features comparable to the "tritt karren" of the Alps (Bogli 1981) are preserved on the paleosurface.

INTERPRETATION

Stress relief sheeting of pre-Ordovician age that formed on a subaerial surface in pre-Paleozoic time is preserved here. It is directly comparable to the subhorizontal sheeting developed in stone quarries as the upper portions are stripped away. This sheeting does not continue into the basal Paleozoic nor is it related to the modern surface. Thin erosional slabs that can be matched to the bedrock beneath are incorporated into the basal Paleozoic sandstone. All these features place the development of the sheeting as pre-Paleozoic and suggest that, in this locality, earliest Paleozoic deposition took place in a very low energy environment.

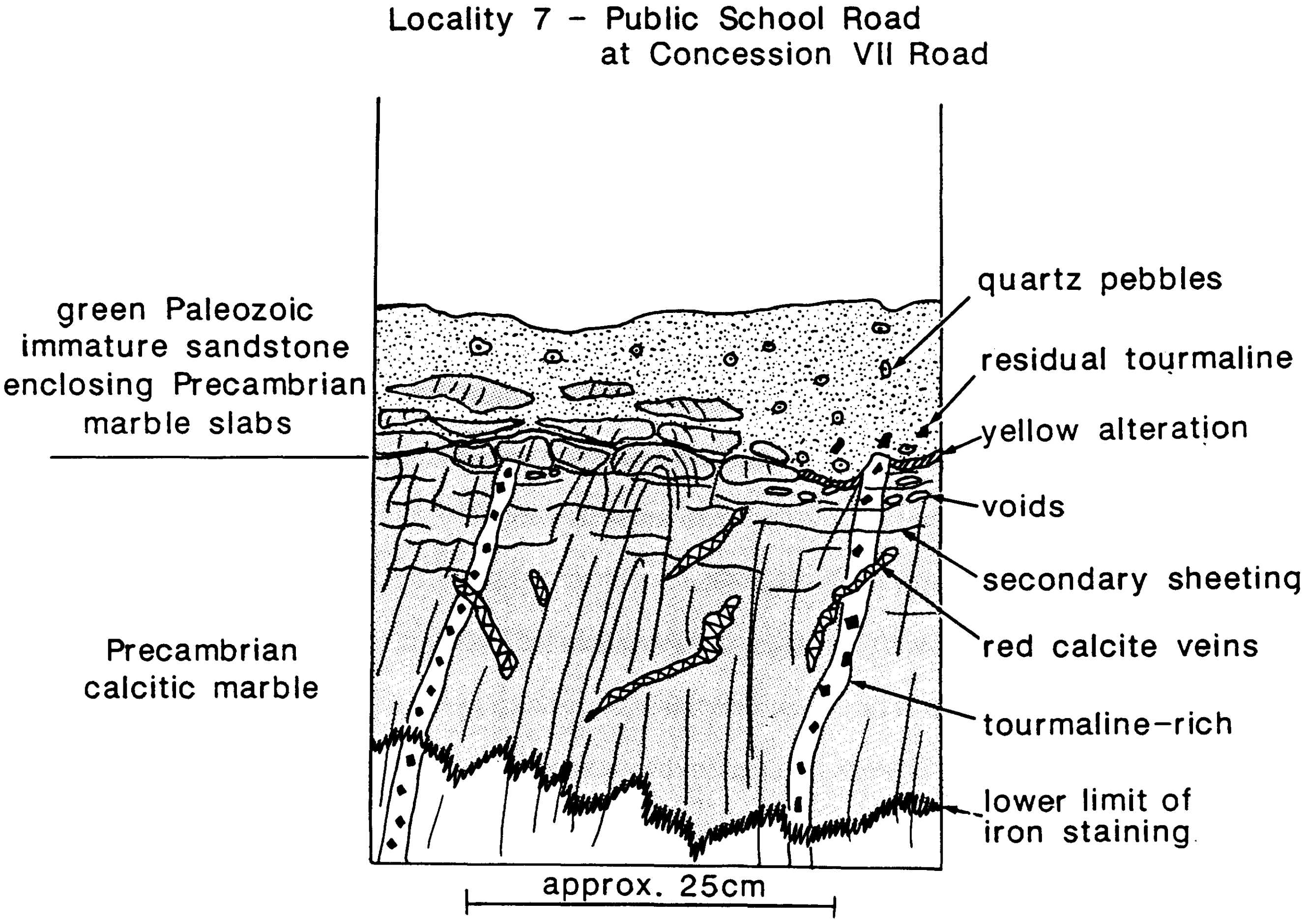


Figure 19: Unconformity features at Public School road at concession VII road (locality 7)

8. SOUTH OF HAZZARDS CORNERS - QUEENSBOROUGH ROAD JUNCTION

OUTCROP CHARACTERISTICS

Karst structure

Increased bedrock porosity

Hematite stain below paleosurface

Resistant residual minerals

LOCATION

Hasting County, Madoc Township, Concession VII, Lot 11

UTM: 18T - E303980, N4937150

Outcrop is on the west side of Concession VIII road, south of the east turn to Queensborough.

DESCRIPTION

The occurrence consists of blue-grey calcitic marble which strikes northeasterly and dips vertically. Metamorphic minerals such as garnet, tourmaline and pyrite occur in specific horizons. A horizontal paleo-erosion surface (Figure 20) is unconformably overlain by green-grey pebbly sandstone with a calcareous matrix. These sandstones are preserved in 2-3 cm diameter, 1-2 cm deep karst hollows (kamenitza) which follow particular horizons in the marble (Figure 20).

Beneath the unconformity surface, the Precambrian bedrock is stained to a depth of 2.5 cm by hematite. Loss of calcite has increased the porosity of this zone. The fine-grained pebbly sandstone that infills the karst hollows consists local materials (tourmaline, garnet and hematized pyrite) derived from the marble and allochthonous subrounded grains of mature quartz (1 mm diameter).

INTERPRETATION

Before the onset of Paleozoic sedimentation, the Precambrian marble was subjected to subaerial erosion weathering and karstification. Surface dissolution pits (kamenitias) developed which were later filled with locally derived detritus and marine Ordovician sand. The paleosurface on the marble is iron stained due to the weathering of pyrite in the marble.

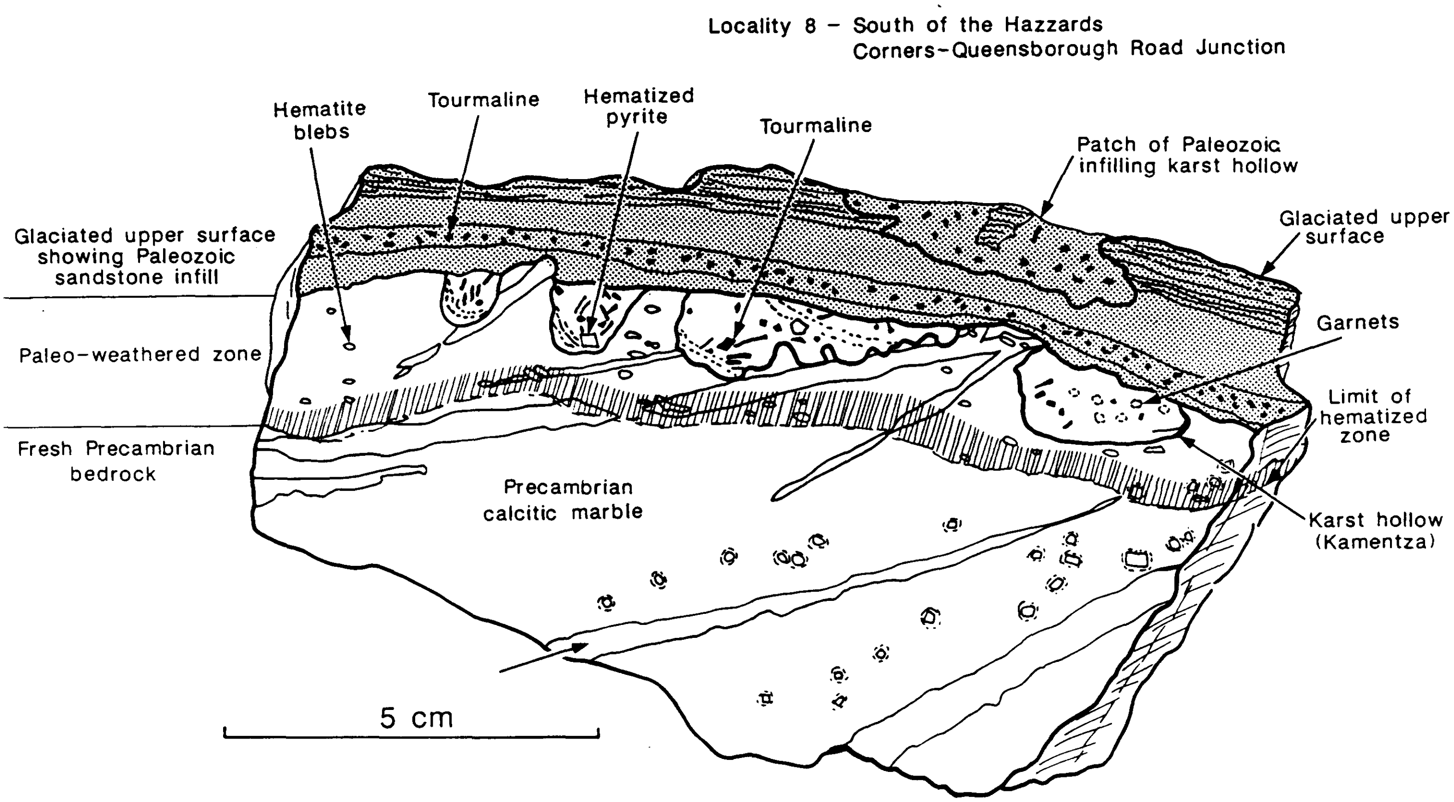


Figure 20: Calcitic marble sample from south of Hazards Corners-Queensborough Road junction showing unconformity features. Sample is cut parallel to foliation (locality 8)

9. HIGHWAY 7, 350 M EAST OF HARTS ROAD

OUTCROP CHARACTERISTICS

Turretted topography

Strong horizontal sheeting parallel to paleosurface

Red staining of marbles

Paleorelief

LOCATION

Hasting County, Madoc Township, Concession IX, Lot 3

UTM: 18T - E307145, N4932530

Outcrops occur north and south of Highway 7, 350 m east of Concession IX road, Hart's Road.

DESCRIPTION

Vertical cliffs, 10-15 m high, expose strongly altered Precambrian marble. South of the road the marble has a strong horizontal sheeting at 0.5-1 m spacings. The strongly foliated, impure dolomitic marble strikes 075°, and dips 90°. Chloritic alteration and wide zones of red staining occur along the horizontal sheets, spreading 2-5 cm below, and 1-2 cm upward from the fractures. Red and green alteration has also occurred along foliation planes and vertical fractures. All these features increase in intensity towards the top of the outcrop. Dissolution has selectively attacked certain horizons leaving overhangs and turrets of remnant marble. On the upper surface of the north outcrops, on the present erosion surface, 10 cm wide seams of hematite-calcite occur.

At locality 2, 350 m to the west, paleosols infill karst hollows in the marble. The paleo-erosion plane can be projected eastward and interpolated to lie about 1-2 metres above the present day surface of the outcrop at this locality (locality 9).

INTERPRETATION

Marble outcrops show karstic dissolution and development of a chloritic alteration on fracture accompanied by a hematitic staining of the marble along the fractures. Recirculation of iron has stained the rocks in the exposed 10 metre section. Loss of calcium carbonate has concentrated the iron minerals. If the weathering effects seen at this locality are compared with the weathering developed on glaciated marble surfaces, it is apparent that post-glacial weathering is neglizible. The strong alteration is therefore interpreted as pre-glacial in age.

The paleo-erosion surface lies within a few metres of the present upper surface of this outcrop. 350 m to the west (locality 2) the unconformity is 10 to 15 metres below the present surface. Thus, there is, at least, 10-15 metres of paleorelief on the erosion surface, and these outcrops are monadnocks on the paleosurface.

The extreme alteration and the turretted landscape reflect pre-Paleozoic weathering beneath the unconformity. Today's land surface is more or less the excavated paleo-erosion surface.

10. GRENVILLE AGGREGATE - MADOC NORTH, HIGHWAY 7 AT HIGHWAY 62

OUTCROP CHARACTERISTICS

Various karst forms controlled by Precambrian structural planes

Paleokarst and recent karst

LOCATION

Hastings County, Madoc Township, Concession V, Lot 3

UTM: 18T - E302345, N4931565

The outcrops lie west of Highway 62, east of the abandoned CNR railway.

DESCRIPTION

The outcrop is a horizontal marble pavement which consists of folded, blue calcitic marble that exhibits several karst features controlled by metamorphic foliation and fracture pattern. Red calcite and calcite-hematite veins occur in the marble and are more resistent to erosion than the host rock.

INTERPRETATION

Red calcite-hematite veins of this type characterize the Precambrian marbles immediately beneath the pre-Paleozoic erosion surface at other localities (e.g. locality 7) where the unconformity is evident. Therefore, the authors interpret the features observed at this locality as pre-Paleozoic karst formed at the unconformity surface and affected by renewed, recent karstification.

11. MOIRA LAKE OUTCROP

OUTCROP CHARACTERISTICS

Erosional pinnacles

Horizontal secondary sheeting

Opaline quartz

Hematite staining below unconformity

Incipient caliche

LOCATION

Hastings County, Huntingdon Township, Concession XIII, Lot 11

UTM: 18T - E303630, N4927285

Outcrops occur east and west of Highway 62 on the small peninsula that divides Moira Lake into east and west portions.

DESCRIPTION

The vertical outcrops along the road consist of strongly foliated, impure dolomitic marble. The marble strikes northerly and dips vertically and exhibits a red stain along WNW striking, 80°NE dipping fractures. Alteration developed in fracture zones (hematite in the marble horizons, chlorite in the more mafic impure skarn bands) is strongly assymmetical. The lower side of the alteration selvages is wider and better developed (Figure 21).

In the vertical outcrop there is a pronounced, sub-horizontal fracture system (spacing of 20-50cm) that becomes more closely spaced toward the outcrop surface. On the east side the fractures are spaced 10-20 cm apart at the base; near the top of the outcrop the rock breaks into flaggy slabs 1-3 cm thick or rods that are 1 cm in cross section and 5-10 cm long and occur parallel to the slabs.

Erosion has selectively worked on horizontal or steeply dipping fracture surfaces, and on foliation planes. Dissolution of calcium carbonate is pronounced in the upper parts of the outcrop and decreases downward. Joint planes have been widened and open zones taper for 10 metres downward. The upper portion of the marble is porous and characterized by pinnacles of remnant marble. Separate open cavities are locally infilled with opaline quartz (Figure 21).

At 6 m below the top of the outcrop, one cavity is filled with fine-grained, mature quartz sand (0.2-0.5 mm sub-rounded grains) with magnetite and ilmenite grains and disseminated hematite. This quartz sand is locally recemented with later red-brown limonite.

INTERPRETATION

The unconformity lies near the top of these outcrops. Steeply-dipping Precambrian fractures have been etched by karsting at least 6 m below the paleosurface where locally mature sands fill karst hollows . Groundwater circulation at the paleosurface has removed calcium carbonate, and has redistributed iron and silica. The zone below the erosion surface is distinctly reddened indicating incipient terra rossa formation. Sheeting has developed parallel to the paleosurface, and calcium carbonate redistribution has produced an incipient caliche profile.

This is an exhumed paleokarst surface on which karsting has resumed. The strong pinnacled relief, the opaline quartz and reddening, differ from the effects of modern karst in this area and are interpreted as a signature of paleokarsting.

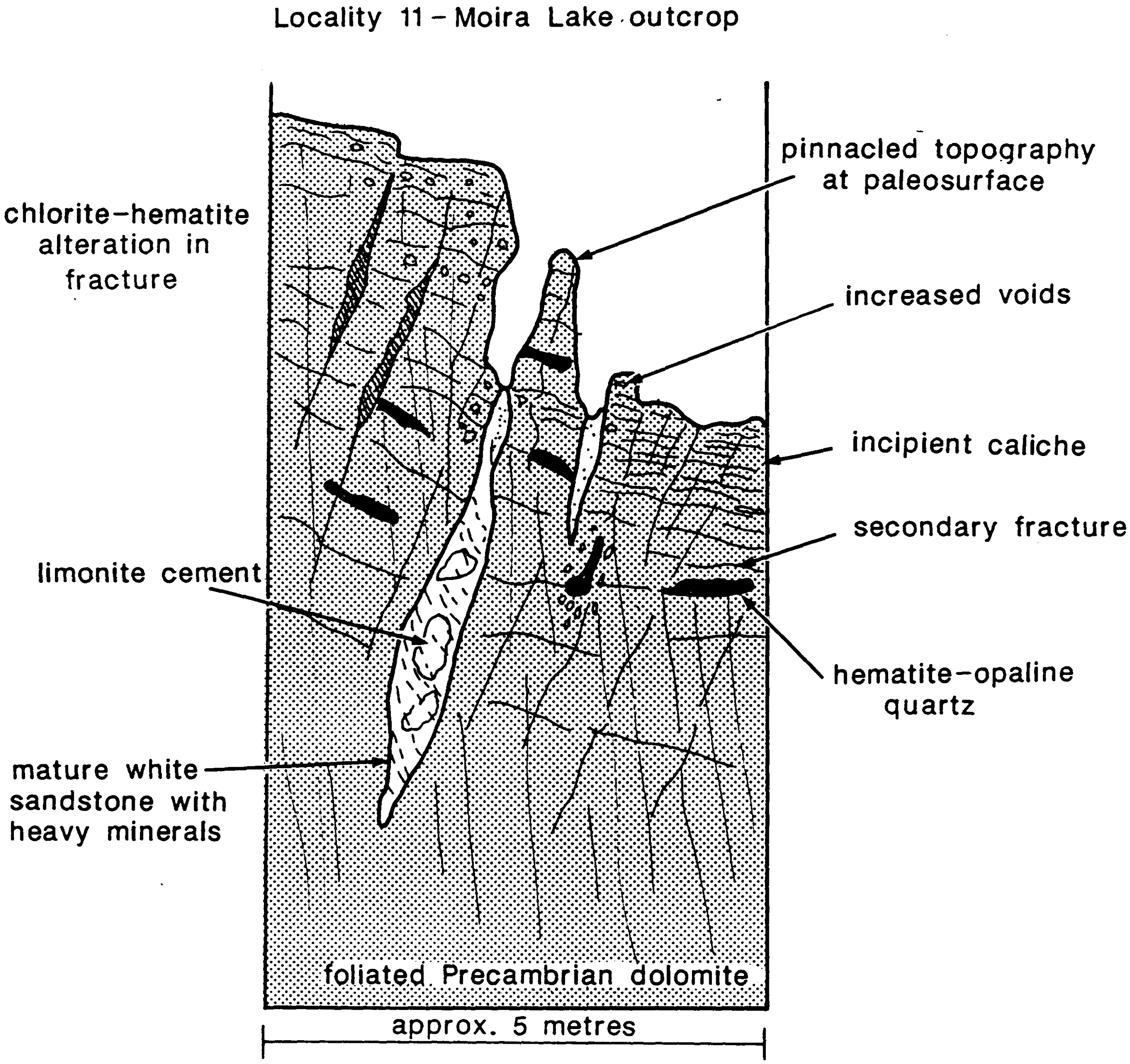


Figure 21: Paleokarst features at the Precambrian-Paleozoic unconformity at the Moira Lake outcrop (locality 11)

12. DEER BAY CREEK

OUTCROP CHARACTERISTICS

Multiple paleosols

Soft soil features

Iron enrichment

Ventifacts

LOCATION

Peterborough County, Harvey Township, Concession 2, Lot ?

UTM: 17T - E718480, N4939660

On the north and south side of Highway 36 are exposures of the unconformity which extend westward for 2 km. Eastward to the intersection with Highway 28 the road lies along the unconformity.

DESCRIPTION

East of Deer Lake, the northern roadcut consists of bleached, in part strongly reddened, amphibole-bearing gneiss. Despite strong chloritization of the mafic minerals and kaolinization of feldspar, the texture of the rocks is preserved, however, the rock is now soft and friable (Figure 22). Twenty metres east and 5 m higher (uphill), the unconformity between the altered gneiss and horizontal Paleozoic sandstone beds is seen (Figure 22). Similar features are seen along the unconformity on the south side of the road. The metamorphic foliation fades gradually upward over a 20-25 cm thickness from a banded, strongly reddened bedrock to a soft, friable, pale amorphous layer which shows crude, subhorizontal layering parallel to the unconformity. The metamorphic layering is smoothly bent downslope in the upper part of the outcrop. Similar structures are seen in modern soil creep. In the upper 15 cm of the amorphous layer many elongate fragments, 2-3 cm long, outline the horizontal layering. They are aligned parallel to the paleosurface. Most consist of dark grey quartz, a few are reddened gneiss. The quartz fragments are shaped like ventifacts (windkanters) and show a dull surface lustre which contrasts with the glassy appearance of freshly-broken surfaces. The dull surfaces show shallow pitting, 0.5 mm across and 0.1 mm deep. The deposits above the unconformity on the southern roadside consist of red and green shale, 2.5 cm thick, capped by 12 cm of fine sandstone which shows load casts on the lower surface (Figure 22). The sandstone horizon is fractured. Fracture planes are stained red and extend through the shale and 5-10 cm into the bleached zone of the uppermost gneiss.

On the northern roadcut the sediments just above the unconformity are a basal Paleozoic sandstone which is banked against a rise in the paleosurface. Above this is a 30 cm thick weathered section of red, iron-rich shale containing iron-coated gneiss fragments. Discordantly above are bedded calcareous shales.

INTERPRETATION

Subaerial weathering of amphibole-bearing gneiss has kaolinized feldspar and caused pervassive reddening of the rock which altered to a soft layer that reaches at least 5 m below the paleosurface. The paleosol contains lag pebble horizons concentrated by water or wind. Pebbles look like windkanters, similar to those found in modern stony desert environments, and suggest wind action.

The paleosurface was evidently soft when the earliest Middle Ordovician sandstone was deposited, as it was compressed beneath the overlying pebbly beds. The paleosol shows solifluction features related to the paleoslope. The deposits immediately above the unconformity record periodic marine incursions with intervals of subaerial exposure during which another paleosol formed. Groundwater circulation oxidized these deposits and redistributed iron. The basal Paleozoic deposits described here differ from the rhythmically bedded shales which constitute the Shadow Lake Formation proper.

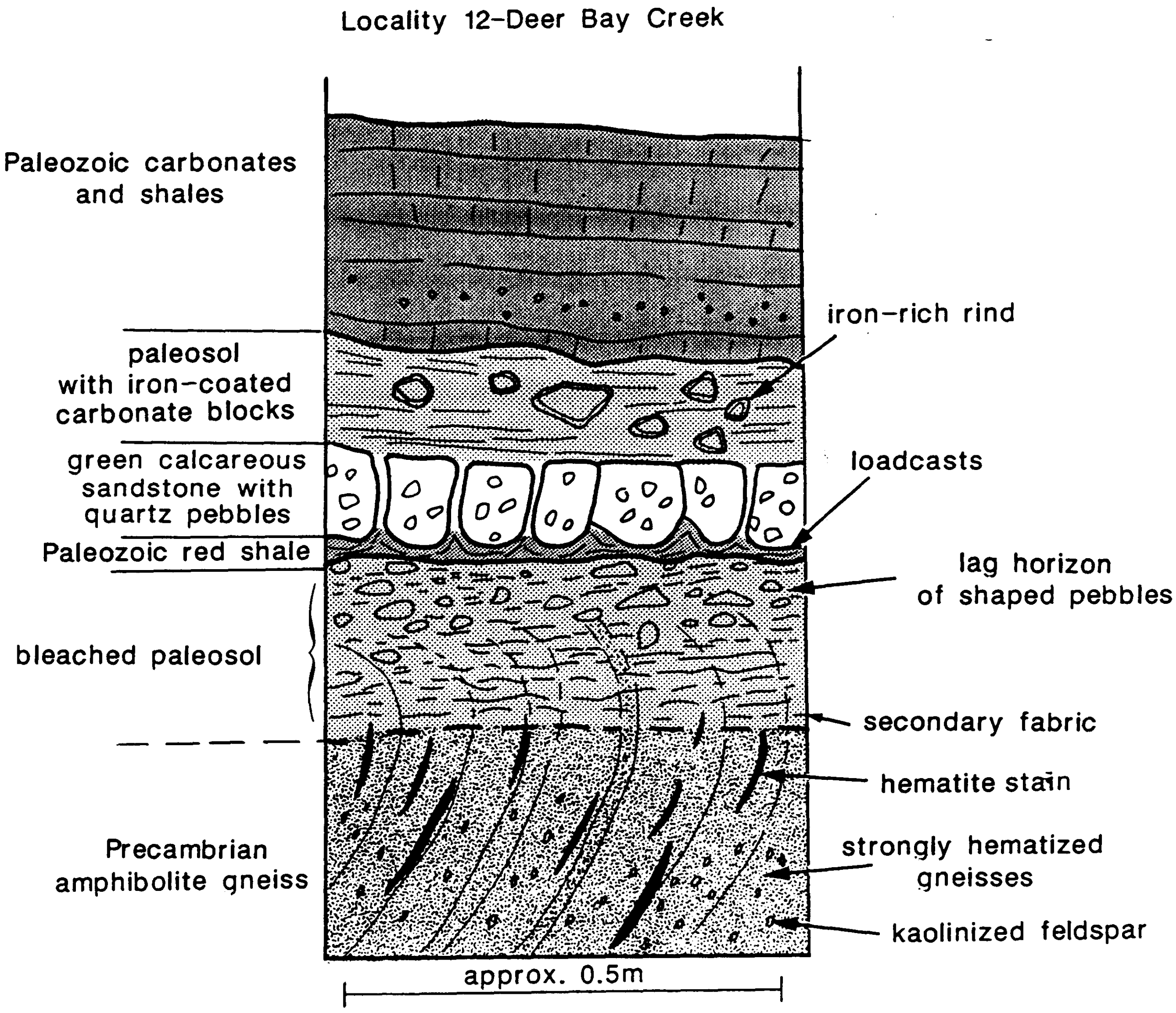


Figure 22: Paleoweathering and solifluction features at the Precambrian-Paleozoic unconformity at Deer Bay Creek (locality 12)

13. HAZZARDS CORNERS QUARRY
(McCOY QUARRY, STOCKLOSAR MARBLE QUARRIES)

OUTCROP CHARACTERISTICS

Silcrete

Iron enrichment

Etched surface on dolomite

LOCATION

Hastings County, Madoc Township, Concession VIII, Lot 12

UTM: 18T - E303950, N4937570

A small quarry east of Concession Road VIII, northeast of the junction with the Public School Road can be seen from the road.

DESCRIPTION

The outcrop consists of pink, flinty dolomite marble with numerous lenses and pods of white quartz. The marble is unconformably overlain by darker, dull red, flinty silcrete that contains fragments of opaline quartz, dolomite crystals eroded from the marble and quartz pebbles (Figure 23). The silcrete caps the outcrop (Figure 23) and a polished slab (Figure 24) shows an a step-like surface with 5-10 cm relief on the marble controlled by joints and metamorphic foliation.

The compositional layering of the marble is shown by trains of rounded chalcopyrite aggregates, and by 2-3 mm sized rhombs of green dolomite. The marble is strongly fractured at 0.5-1 cm intervals parallel to the paleo-erosion surface. A dark red stain is present along the fractures in a zone 20-30 cm deep below the erosion surface.

Silcrete fills small karst depressions in the dolomite marble. It encloses residual dolomite fragments and green dolomite rhombs from the bedrock below. Sub-horizontal banding in the silcrete abuts against the depression walls. The silcrete consists of dark grey glassy silica which has been overprinted with secondarly cement of jaspery silica. The upper part of the outcrop has been recently weathered; it is porous and limonitic.

INTERPRETATION

A Precambrian silcrete on dolomite marble marks the Late Proterozoic-Early Cambrian period of weathering. The first deposits above the unconformity vary across the erosion surface. 500 m south of this locality, at locality 8, fine calcareous sandstone marks the base of the Paleozoic.

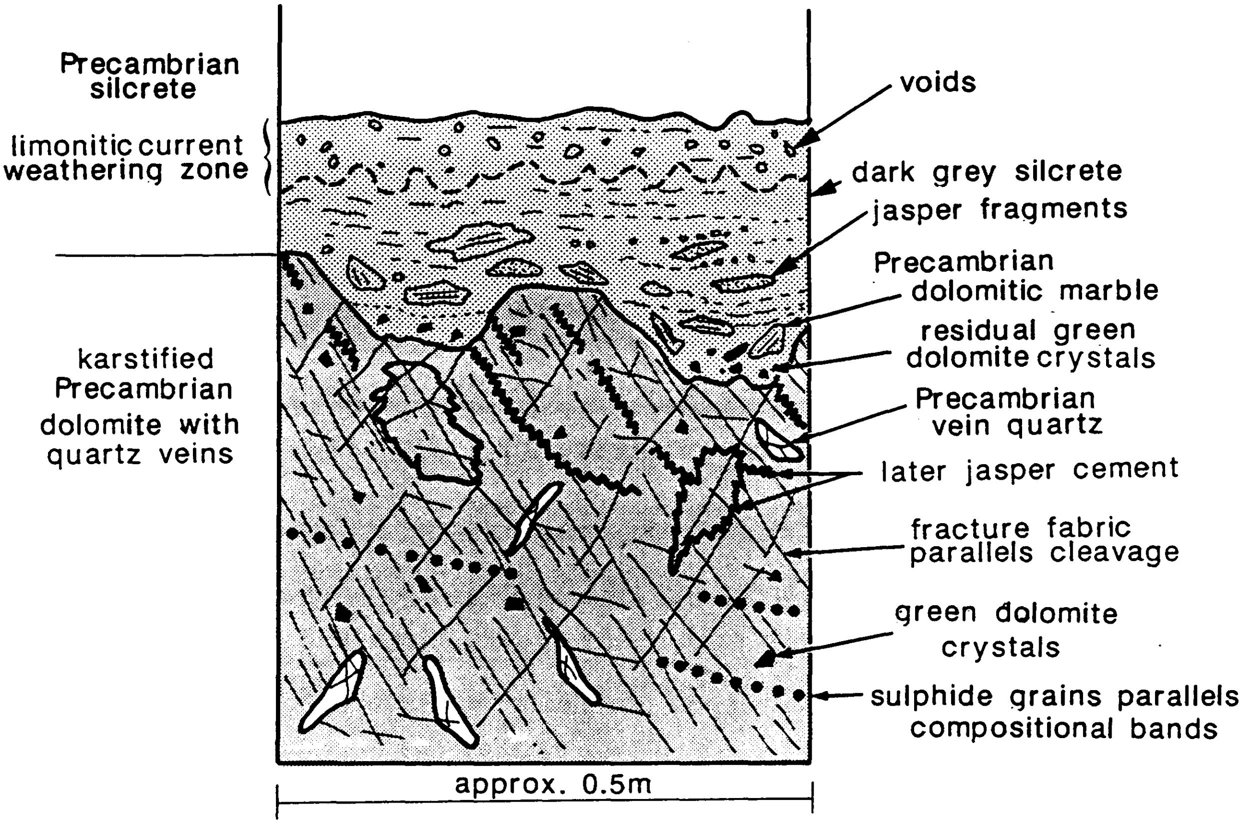


Figure 23: Karstic erosion and silica-iron residues on the unconformity surface at the Hazards Corners quarry (locality 13)

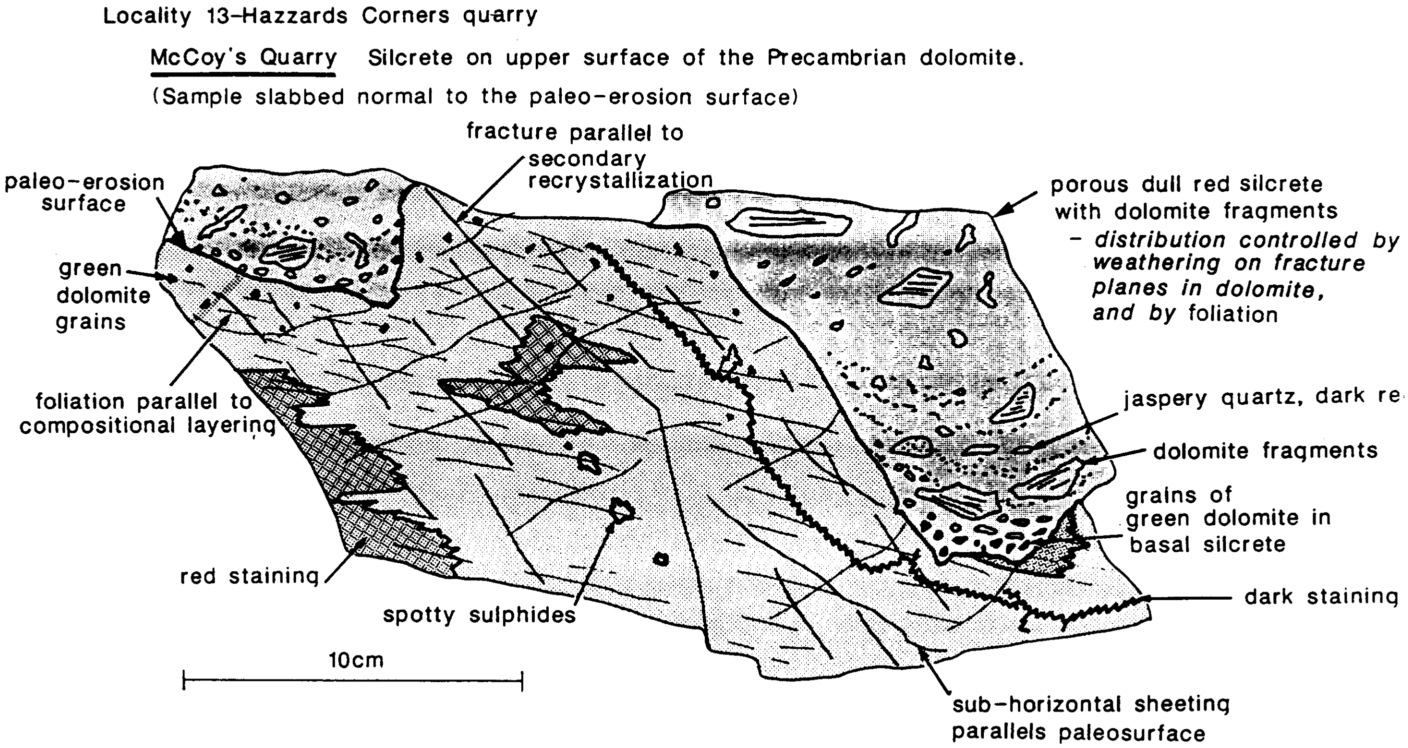


Figure 24: Rock sample showing unconformity features at the Hazards Corners Quarry (locality 13).

14. WALLBRIDGE IRON MINE

OUTCROP CHARACTERISTICS

Paleoregolith, collapsed gossan

Supergene reconcentration (Fe, Ca)

Epiclastic mineralization

LOCATION

Hastings county, Madoc Township, concession V, lot 12,

UTM: 18T - E300920, N4937090

The Wallbridge iron mine is easily accessible by Highway 62, and occurs on the west side of the highway, about 7 km north of the town of Madoc, immediately south of the intersection with the "Hemitite road".

DESCRIPTION

Hematite ore was mined, at the turn of the century, from an open pit about 50 m in diameter and 20 m deep (Rose 1958). A hematitic gossan several metres thick capped a magnetite skarn ore body occurring in Precambrian dolomitic marble. The Precambrian iron ore, in turn, is capped by several metres of sandstone, sandy-limestone, and limestone (Figure 25). The best exposures of the Precambrian-Paleozoic contact as well as the mineralization are exposed along the west side of the open pit (Figure 25). The marble which strikes east-west, has lenses of hematite and magnetite with a few sulphide crystals. Above the iron ore, there is an elongated depression running east-west, where, first, a detrital subaerial regolith (coarse conglomerate), and second, Middle Ordovician clastic marine sediments were deposited (Figure 25).

In the open pit, the paleoregolith between the Precambrian iron ore deposit and the Middle Ordovician rocks, is clearly visible in the southermost part of the west side.

Its thickness ranges from 0.7 to 1.0 m , and it is made up mostly of marble fragments and secondarily of iron ore and quartz fragments, ranging in size from 1 mm to about 5 cm (Figure 25). Fragments of the marble and iron ore are cemented by iron oxide and carbonate. The colour is light brown to whitish, except in the stongly-oxidized sections where it becomes red brown.

INTERPRETATION

Iron oxide was reconcentrated above the Precambrian skarn iron ore deposit by supergene processes, forming a soft iron oxide-bearing weathered gossan horizon several metres thick (Figure 26). The gossan was in part disintegrated by erosion and collapsed, creating a depression where a subaerial detrial blanket formed above the iron ore deposit (Figure 26). The paleoregolith, which is a paleosol, was deposited before Middle Ordovician sedimentation, between the Late Proterozoic and the Early Paleozoic, and was in part cemented by remobilized iron oxide (Figure 25). Because of the weathering at the zone of unconformity, the rocks just above and under the unconformity surface had a high degree of permeability and porosity. Iron-bearing fluid circulated in the open spaces, producing iron-oxide replacement of marble fragments, and cementation of the detrital rocks namely the conglomeratic regolith and the Middle Ordovician sandstone above the Precambrian iron ore (Figure 26). This site shows that iron reconcentration from the original Precambrian iron skarn body occurred several times from the Late Proterozoic to the Early Paleozoic (Figure 26).

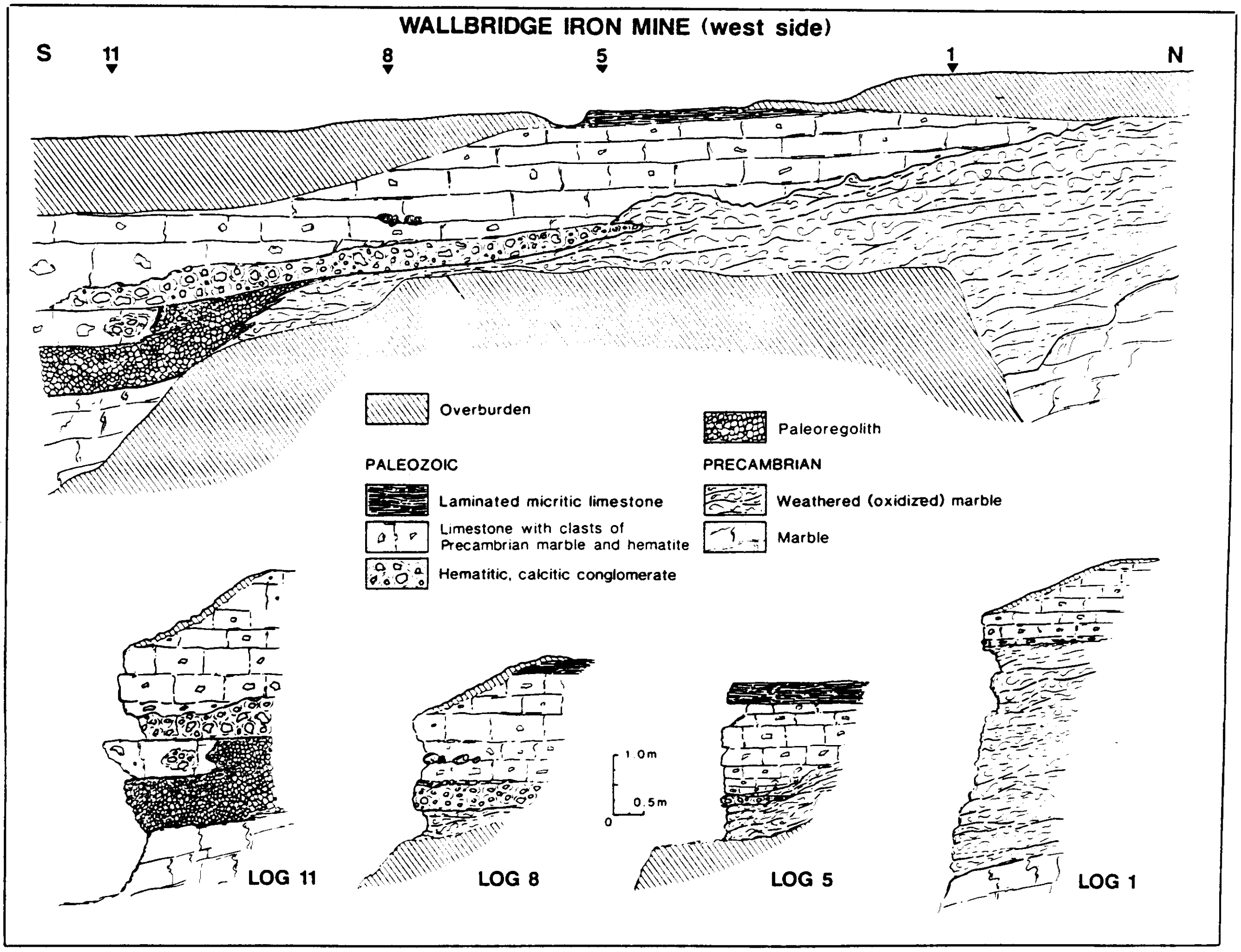
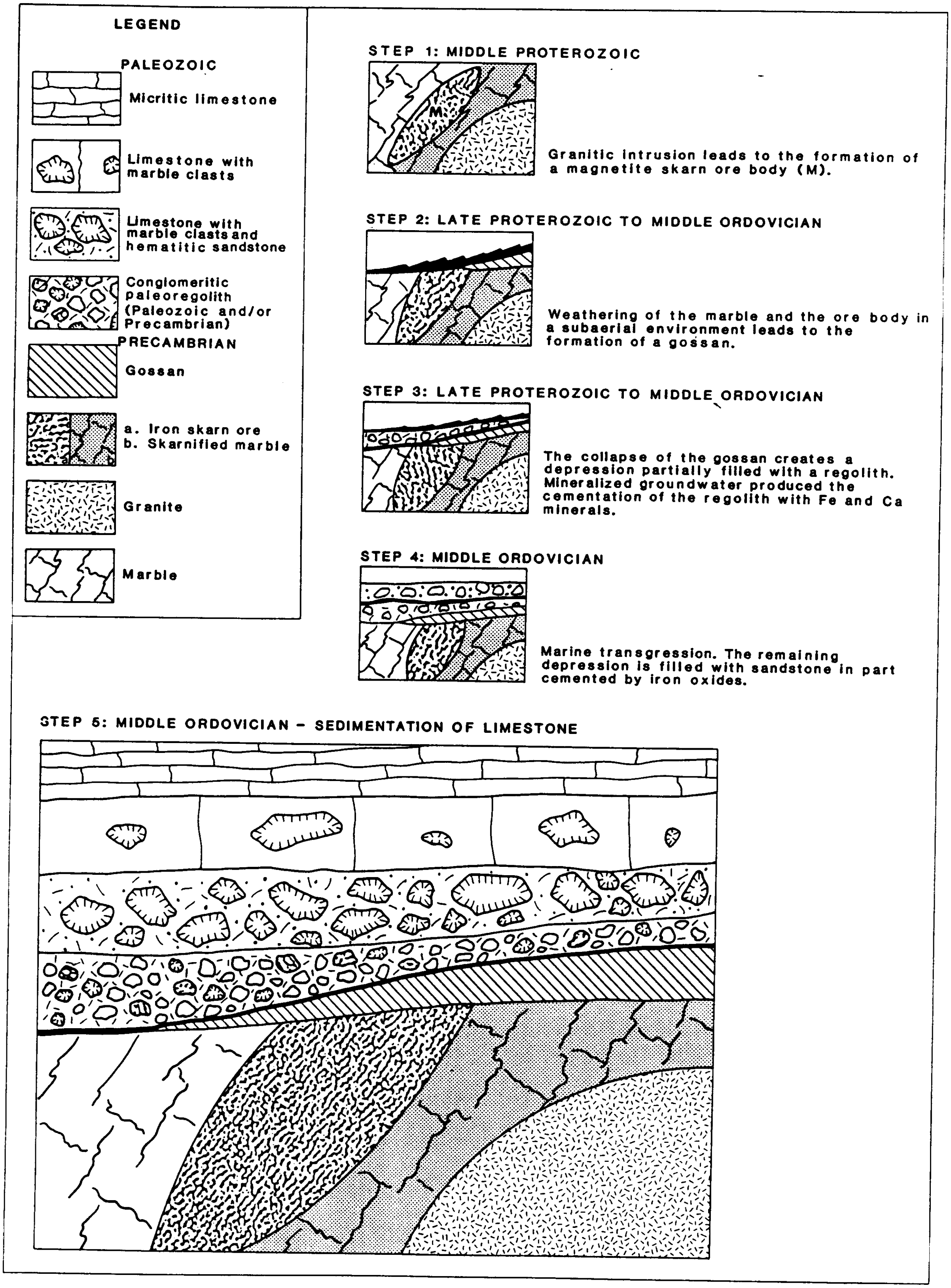


Figure 25: Profile of the west side of the open pit at Wallbridge iron mine (locality 14).

Figure 26: Interpretation of the unconformity at the Wallbridge iron mine (locality 14).



STEP 1: MIDDLE PROTEROZOIC

Granitic intrusion leads to the formation of a magnetite skarn ore body (M).

STEP 2: LATE PROTEROZOIC TO MIDDLE ORDOVICIAN

Weathering of the marble and the ore body in a subaerial environment leads to the formation of a gossan.

STEP 3: LATE PROTEROZOIC TO MIDDLE ORDOVICIAN

The collapse of the gossan creates a depression partially filled with a regolith. Mineralized groundwater produced the cementation of the regolith with Fe and Ca minerals.

STEP 4: MIDDLE ORDOVICIAN

Marine transgression. The remaining depression is filled with sandstone in part cemented by iron oxides.

STEP 5: MIDDLE ORDOVICIAN - SEDIMENTATION OF LIMESTONE

15. COE IRON MINE (ELDORADO COPPER MINE)

OUTCROP CHARACTERISTICS

Gossan

LOCATION

Hastings county, Madoc Township, concession V, lot 17

UTM: 18T - E299230, N4939790

The Coe iron mine occurs on top of a low ridge about 1 km west of the village of Eldorado.

DESCRIPTION

The mine was operated at the turn of the century producing hematite ore and copper (Corkill 1906). The ore body is a skarn deposit occurring at the contact of Precambrian granite and marble. Along this contact, a thick gossan formed on a wide, east-west, open fissure. Chalcopyrite and minor chalcocite were found under a hematite capping of about 25 m thickness. Scattered small patches of reddish coarse Paleozoic sandstone crop out at the edge of the ridge where the mine occurs.

INTERPRETATION

Pre-Middle Ordovician weathering affected the Precambrian sulphide skarn deposit, generating a gossan at the upper part of the ore body. Near the surface, collapse of the weathered ore deposit occurred under the combined effect of downward leaching of elements downward, the dehydratation of hydrated iron oxide to hematite, and the dissolution of carbonate host rocks by acidic solutions produced by the weathering of sulphides.

Although the gossan at the Coe Iron Mine is not sealed under Paleozoic sediments, it shows, nevertheless, the same characteristics as other gossans preserved under Paleozoic rocks (Wallbridge iron mine, Blairton iron mine, Cook mine) (Figure 27). In these ore deposits, the thickness of the weathering above the primary ore bodies ranges from a few metres up to twenty-five metres. Other mineralization occurring with iron are manganese, silica, uranium, and gold. It is likely that all the gossans in the Madoc-Marmora area formed in the same way at the same time.

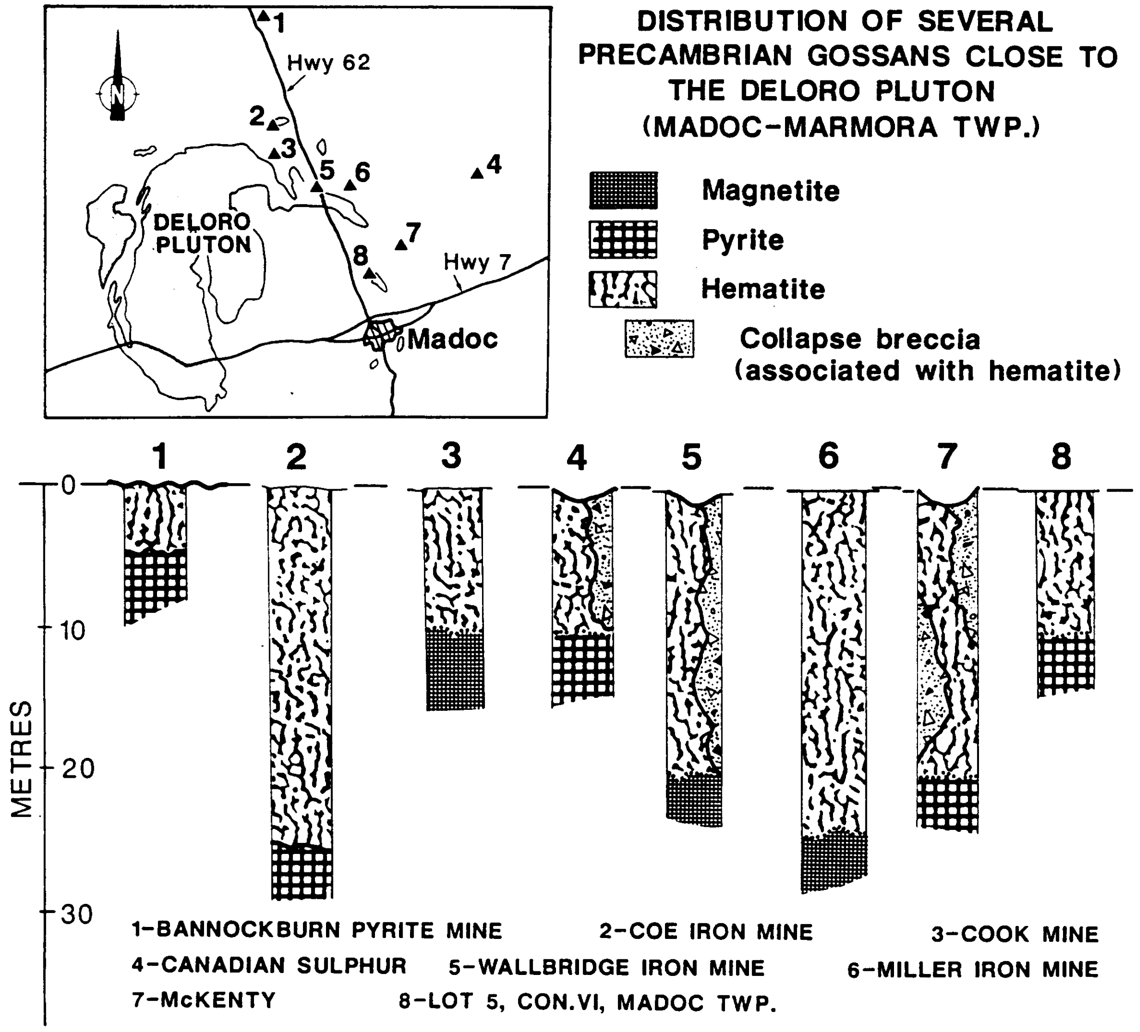


Figure 27: Distribution and profiles of Precambrian gossans close to the Deloro Granite.

16. FURNACE FALLS OCCURRENCE

OUTCROP CHARACTERISTICS

Lithified, laterite-like regolith

LOCATION

Haliburton county, Snowdon Township, concession II, lot 19

UTM: 17T - E692880, N4967100

The Furnace Falls occurrence lies about 10 km northeast of the village of Kinmount. Access to the site is by Highway 503, 1 km north of Irondale River. The occurrence lies on the west side of the road behind a farm.

DESCRIPTION

At this site, a lithified regolith is developed on pyrite-bearing calcitic dolomite marble that is overlain by glaciofluvial sands of Pleistocene age. According to Easton (1987), a composite vertical section through the regolith from bottom to top is as follows:

1 - pyrite-bearing, blue - gray massive calcitic dolomite marble (83RME-471G, Table 15).

2 - a zone of up to 2 m thick of red-stained , iron rich weathered rock, overlying the marble (83RME-471C, Table 15).

3 - a zone, 1 to 2 m thick of lithified, stained and altered, bright-red oxidized sand derived from the overlying Pleistocene deposits. This zone stikes northeast, is the most visible manifestation of this occurrence, and outcrops over a lenght of 200 m. The lateral extent of this zone is unknown, but probably continues both northeast and souteast under unaltered glaciofluvial sand and gravel (83RME-471D, Table 15).

4 - unweathered, unoxidized glaciofluvial sand and gravel overlies the marble and the weathered rocks (83RME-471E, Table 15).

Outcrops are exposed in a relatively flat, low area, adjacent to a ridge of Precambrian quartzite. In the weathered oxidized zone, above the unaltered Precambrian marble, there is a strong enrichment of iron up to 36%, accompanied by an increase of the aluminium and titanium content while magnesium, calcium, copper and zinc are depleted. The interface between unaltered marble and the oxidized horizon shows the same geochemical evolution and as well as a slight gold enrichment. Similar strongly altered zones occur at several other localities in this area. Easton (1987) mentions: "A similar gossan zone is found on the farm of Robert Hughes, Lot 10, Concession 18, Galway Township. This property is reported (Satterly 1943) to have a 0.3 to 1.3 m thick gossan horizon extending over a strike length of 75 m which is developed on pyritiferous marbles, and which is also covered, in part, by glaciofluvial deposits of the Irondale River Valley. The Hughes occurrence may be developed over the extension to the southwest of the same stratigraphic horizon as at Furnace Falls".

INTERPRETATION

The topographically low setting of the occurrence contributes to the preservation of the outcrops from the erosive action of the Pleistocene glaciation. The flat disposition of the occurrence has led to a strong "in situ" chemical alteration of a large mass rock, forming a relatively thick oxidized horizon, enriched in iron and aluminium, above Precambrian metasediments. This strong weathered cap resembles those observed in laterite profiles in tropical areas (Le Count Evans 1981; Mann 1984; Michel 1987).

Table 15: Geochemical assays from the Furnace Falls Occurrence. From Easton (1987)

ELEMENT	UNALTERED MARBLE	INTERFACE MARBLE-WEATHERED ROCK	WEATHERED METASEDI-MENT	UNLITHIFIED DETRITAL SANDS
%	83RME-471G	83RME-471C	83RME-471D	83RME-471E
Aluminium	1.12	1.89	1.54	1.51
Calcium	0.81	0.41	0.37	0.82
Copper	0.03	0.01	0.02	0.00
Iron	16.46	30.38	36.59	4.14
Magnesium	0.79	0.11	0.09	0.76
Titanium	0.13	0.2	0.16	0.19
Zinc	0.01	0.00	0.00	0.00
Gold (ppb)	0	11	0	0
Silver (ppm)	..6	.1	4	.0

17. MONO GOLD MINE

OUTCROP CHARACTERISTICS

Supergene Reconcentration (Mn, Fe, Au)

LOCATION

Hastings County, Madoc Township, concession VI, lot 29,
UTM: 18T - E297850, N4946475

The Mono gold mine is about 1 km east of Highway 62 north, immediately north of the Town of Bannockburn.

DESCRIPTION

Gold-bearing quartz veins cut Precambrian pelitic and rusty schists and mafic metavolcanics. The ore deposit was discovered by Mono Gold Mines Incorporated in 1984 and in 1987 the Quaternary overburden was stripped over a large area, exposing an undulating topography (from 0.5 m to 2.5 m amplitude), similar to a karst surface. At the bottom of depressions above the Precambrian, crusts, up to 15 cm thick, occur of red-brown to dark black earthy material; and seams, up to 15 cm wide, of the same earthy material infills cavities beneath the paleosurface. Mineralogical and geochemical examination indicate that the earthy material is made up of small fragments of quartz and metasediment (> 1 cm) cemented by iron and manganese oxide. Gold, up to 125 ppb, is present with the oxides.

INTERPRETATION

The present surface is likely the original Precambrian paleokarst surface. Oxidation and supergene processes affected the paleosurface, and at low points, thin crusts of iron and manganese oxide and gold were deposited. Manganese oxide wads have been observed elsewhere in Madoc Township (MacFarlane 1866).

18. 19. CORDOVA AND DIAMOND GOLD MINES

OUTCROP CHARACTERISTICS

Secondary Supergene Reconcentration (Fe, Au)

LOCATION

Cordova (Belmont) Mine:
Peterborough County, Belmont Township, concession I, lot 20
UTM: 18T - E278710, N4935150
Diamond (Sophia) Mine:
Hastings County, Madoc Township, concession X, lot 14
UTM: 18T - E306770, N4939935

The Cordova gold mine is accessible by Peterborough County Road 48, and is situated about 350 m south of the road, at the edge of the town of Cordova Mines. The Diamond gold mine occurs 500 m north of Hastings County Road 20, immediately west of Railway Creek about 1.5 km west of the town of Queesborough.

DESCRIPTION

The Cordova and the Diamond (Sophia) mines, are two gold mines discovered in southeastern Ontario at the end of the nineteenth century (Blue 1894, Slaght 1898, Gibson 1937). At the Cordova mine, gold was found in several quartz-ankerite veins carrying pyrite, chalcopyrite, and a minor amount of pyrrhotite, hosted in the Cordova gabbro (Blue 1894, Carter 1984) (Figure 28). The Diamond (Sophia) mine (Slaght 1898) consisted of a quartz vein carrying arsenopyrite, pyrite and gold; cutting mafic metavolcanic rocks of the Tudor Formation (Figure 29).

In both mines, Blue (1894), and Slaght (1898), indicate that near surface, the quartz veins were strongly altered for several metres and decomposed into earthy brown iron oxide mixed with siliceous matter and free gold. At both mines, scattered patchy outcrops of Paleozoic sandstone and siltstone crop out near the Precambrian mineralized veins.

INTREPRETATION

The primary quartz-sulphide veins which cut the Cordova gabbro have been altered by oxidation which decreases in intensity downward. The resulting minerals are hematite-bearing free gold, and secondary quartz. Alteration of the sulphides has produced limonitic alteration products.

The authors believe that the alteration affecting the uppermost zone of the veins is primarly pre-Middle Ordovician in age. Before the Middle Ordovician, the mineralized veins were weathered at the Precambrian paleosurface. Most of the minerals were oxidized and leached downward toward the zone of supergene reconcentration. In a leached horizon, close to the unconformity surface, fragmented quartz veins containing iron oxide, silica and free gold liberated from the gangue remain. The paleoweathering features were covered by Paleozoic marine sediments. The unconformity surface wasexhumed by removal of the Paleozoic cover, and modern weathering, with limonite alteration products, is taking place presently.

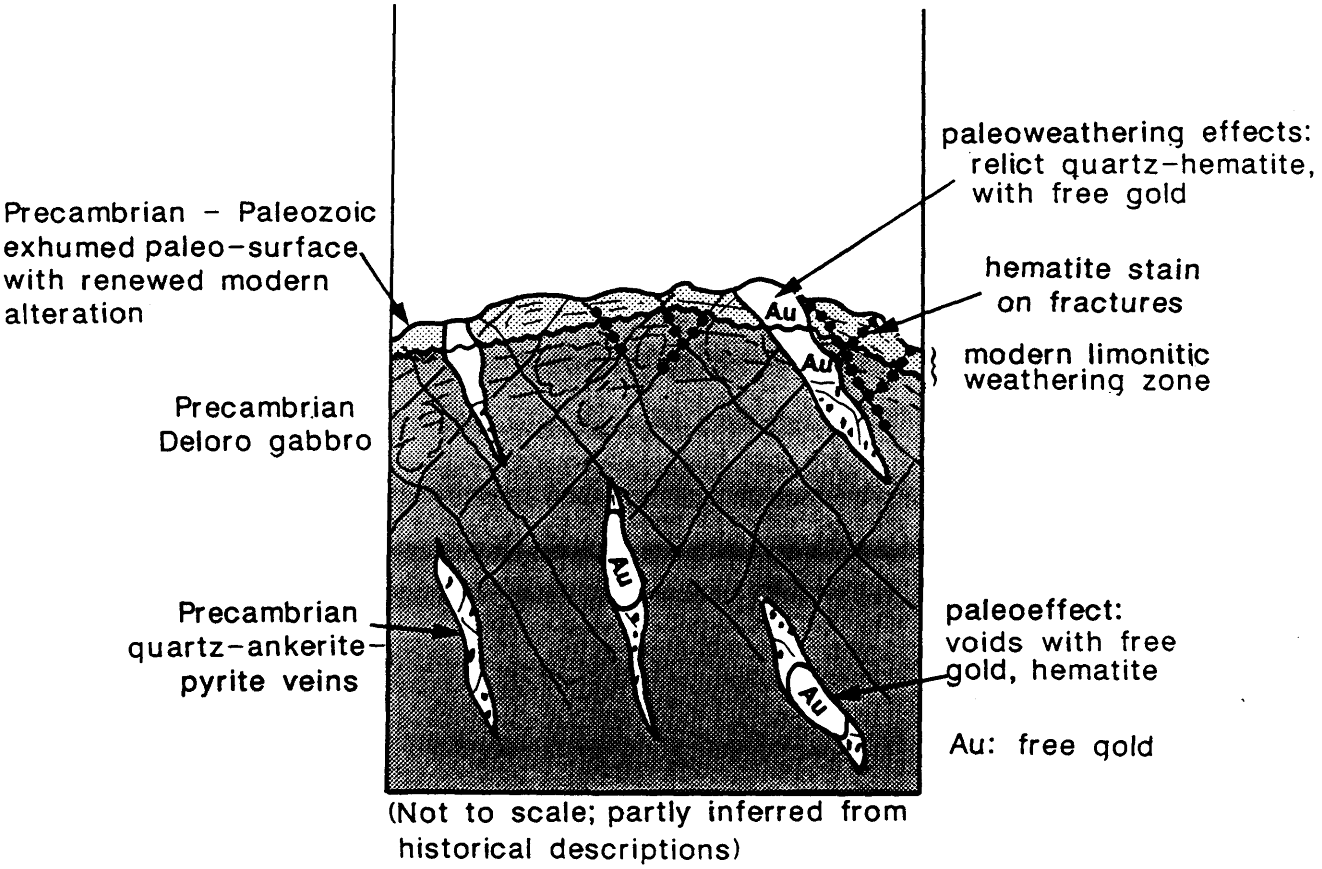


Figure 28: Features of modern and pre-Paleozoic weathering at the Cordova gold mine and Cordova north occurrence (localities 18 and 27).

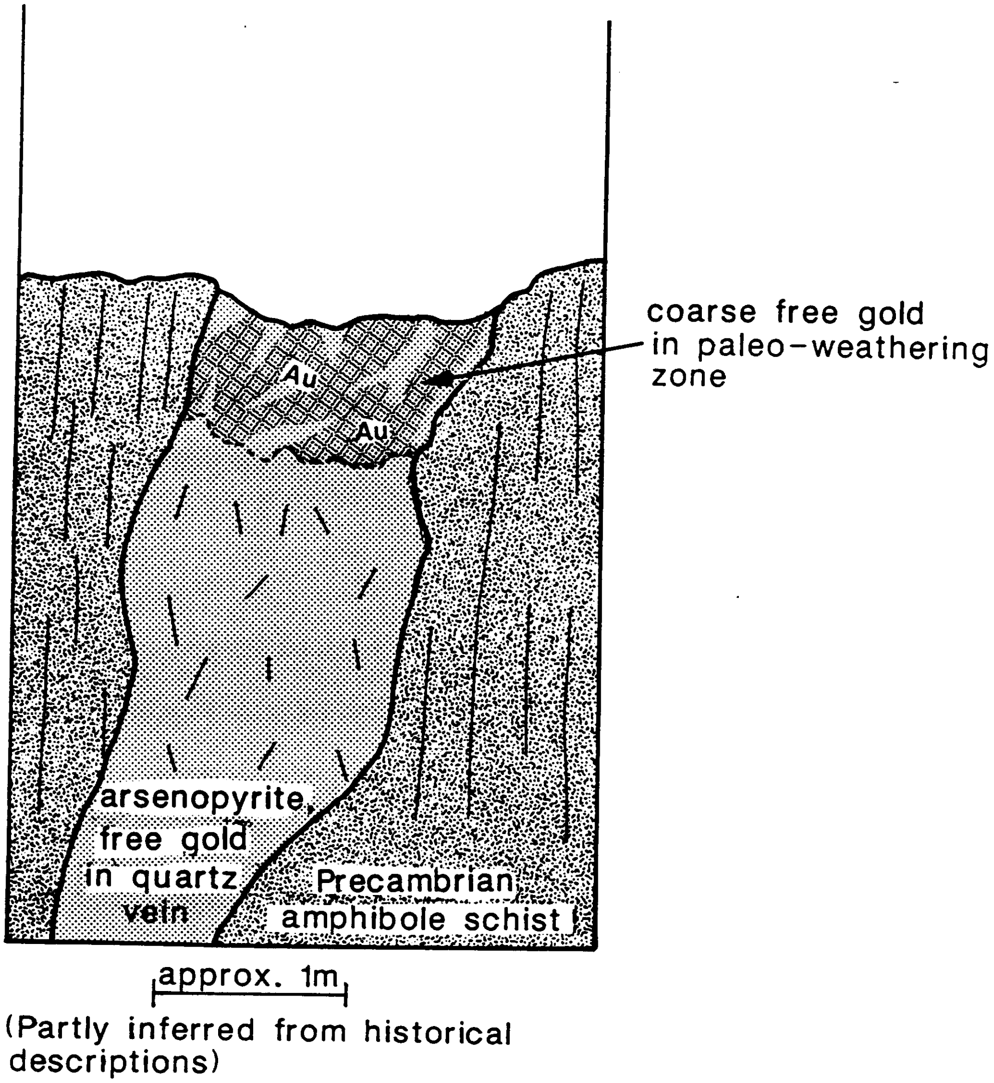


Figure 29: Secondary gold enrichment in a paleoweathering zone at the Precambrian-Paleozoic unconformity at the Sophia (Diamond) gold mine (locality 19).

20. BLAIRTON IRON MINE

OUTCROP CHARACTERISTICS

Paleoregolith, gossan

Supergene reconcentration (Fe, Ca, Si)

LOCATION

Peterborough county, Belmont Township, concession I, lots 7 and 8,

UTM: 18T - E280260, N4927390

The Blairton iron mine is located on the southwest shore of Crowe Lake, approximately 7 km west of Marmora.

DESCRIPTION

A skarn magnetite iron ore deposit occurs in marble and minor chloritic schist intruded by a gabbro-diorite body. Paleozoic conglomerate, dolomite, and limestone unconformably overlie the Precambrian basement.

The setting of the unconformity at the Blairton mine is very similar to the Wallbridge iron mine (occurrence 14). A paleoregolith up to 1.5 m thick is preserved on the northwest corner of the southernmost pit (Morton pit). It is made up of fragments of Precambrian iron ore (magnetite and maghematite) and metasediment both cemented by iron oxide, carbonate and silica (Figure 30). Abundant clasts of magnetite also occur in the basal Paleozoic conglomerate which unconformably overlies both the Precambrian paleosurface and the iron skarn (Figure 30).

INTERPRETATION

As at the Wallbridge iron mine, supergene processes, aided by groundwater, have leached and redeposited iron, calcium, and silica in the paleoregolith. Iron oxides, mainly hematite, occur as cement and replace marble fragments.

Locality 20': Dufferin Mine

Similar mineralization occurs at the Dufferin mine located on lot 18, concession I, Madoc Township, Hastings County. Red hematite and maghemite fragments are abundant in the basal Paleozoic conglomerate which overlies a Precambrian magnetite skarn deposit occurring in calcitic marble (Figure 31). Cylindrical bore holes from 2 to 4 mm in diameter occur in the basal Paleozoic rocks and in the upper weathered horizon of the Precambrian deposit (Figure 31).

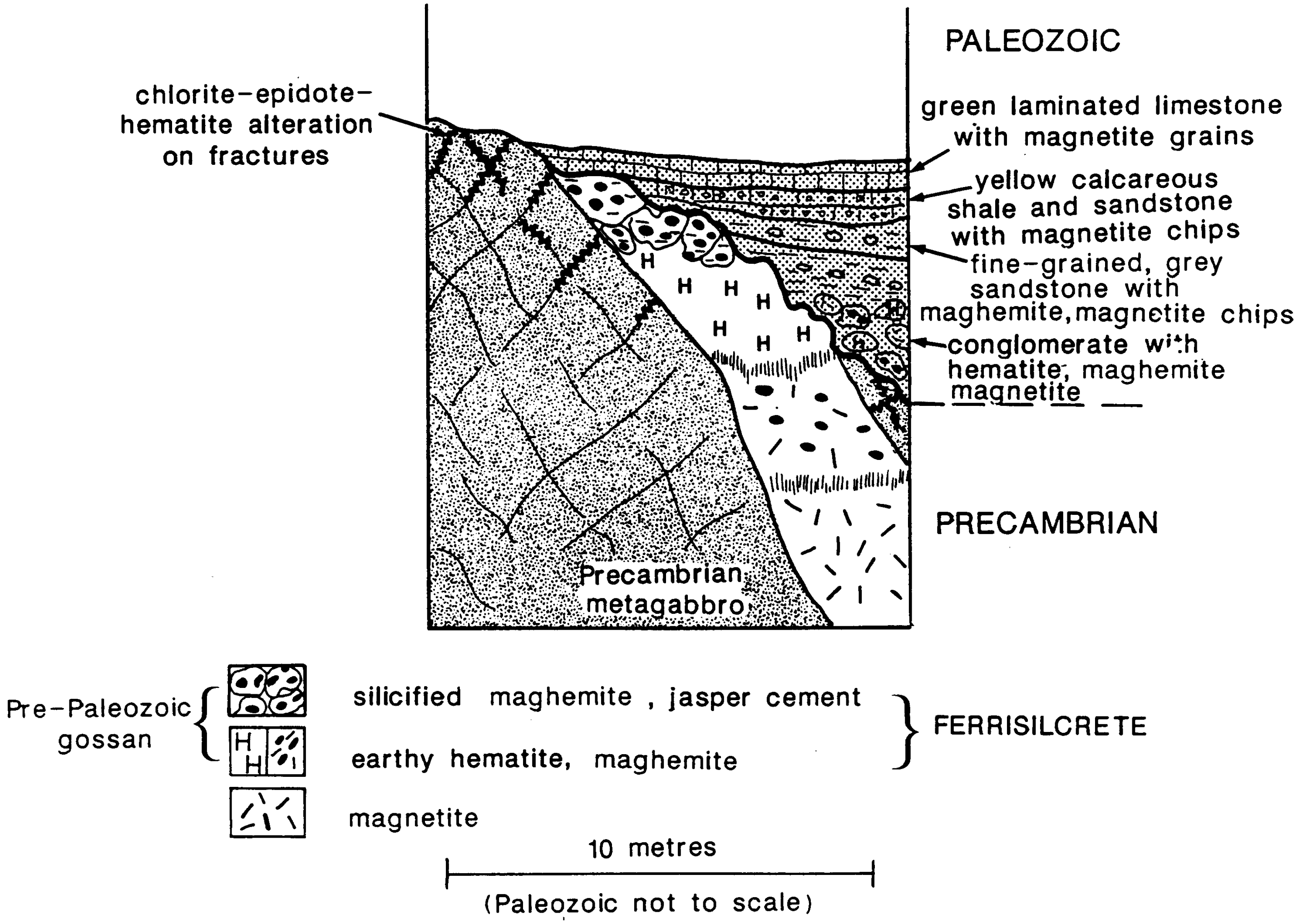


Figure 30: Magnetite ore with pre-Paleozoic gossan incorporated into basal Paleozoic sediments at the Blairton iron mine (locality 20).

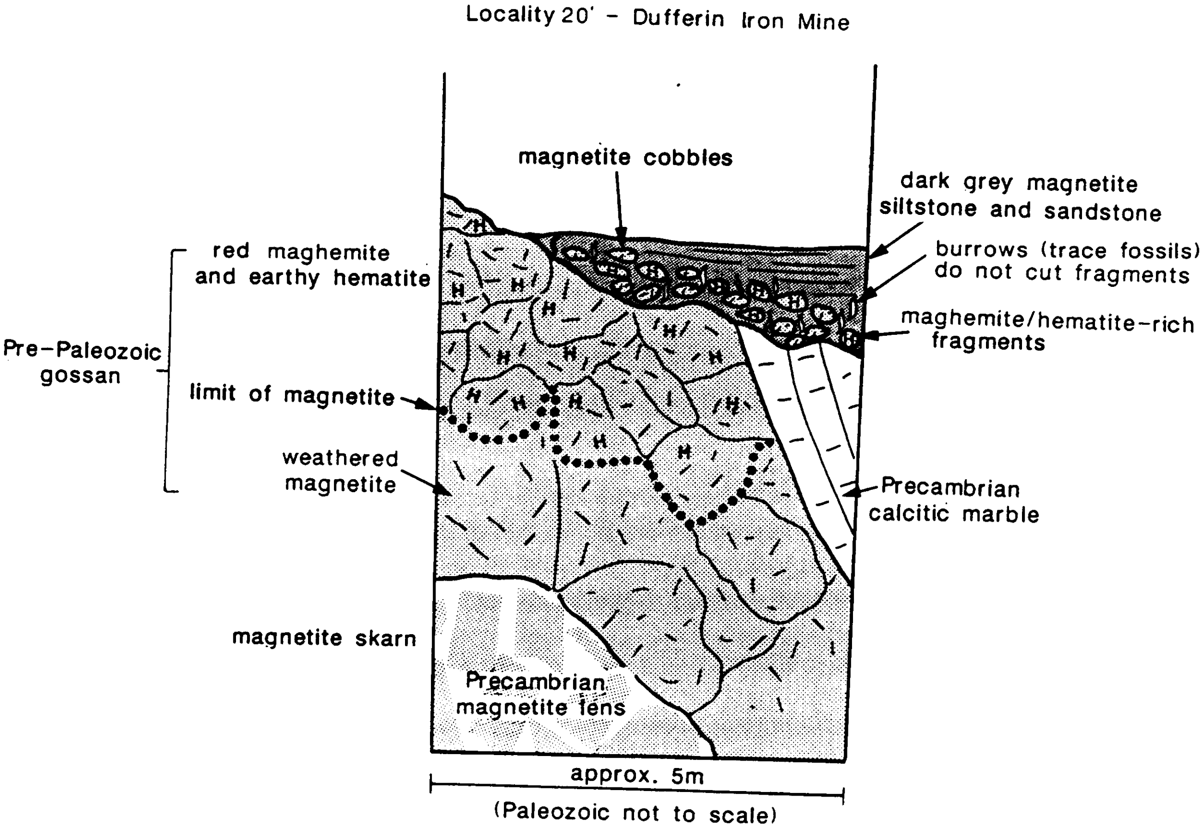


Figure 31: Unconformity features at the Dufferin iron mine (locality 20').

21. HASTINGS COUNTY ROAD 11 OCCURRENCE

OUTCROP CHARACTERISTICS

Dissolution cavities

Supergene reconcentration of Fe, U, Ti

LOCATION

Hastings County, Madoc Township, concession IX, lot 13

UTM: 18T - E291455, N4934690

Along Hastings County Road 11; 2.5 km north of the town of Deloro, a small trench about 25 m west of the road is exposed.

DESCRIPTION

The trench is in marble, immediately west of the Deloro Granite, a few metres from red Paleozoic sandstone and shale. The northeast side of the trench exposes a pervasive oxidation in the marble. The uppermost 5-15 cm of the marble contains small crevices a few millimetres wide, some of are filled with red earthy material which is strongly radioactive (Figure 32). Mineralogical identification of the radioactive material (B.Hicks, Geoscience Laboratories, Ontario Geological Survey) reveals the presence of brannerite (U, Ca, Ce) $(TiFe)_2O_6$, associated with ilmenite.

INTREPRETATION

Uranium and titanium were probably leached from the nearby pluton and precipitated in small dissolution cavities occurring at the unconformity surface. Middle Ordovician sandstone and shale covered the Precambrian rocks, preserving the original weathering profile.

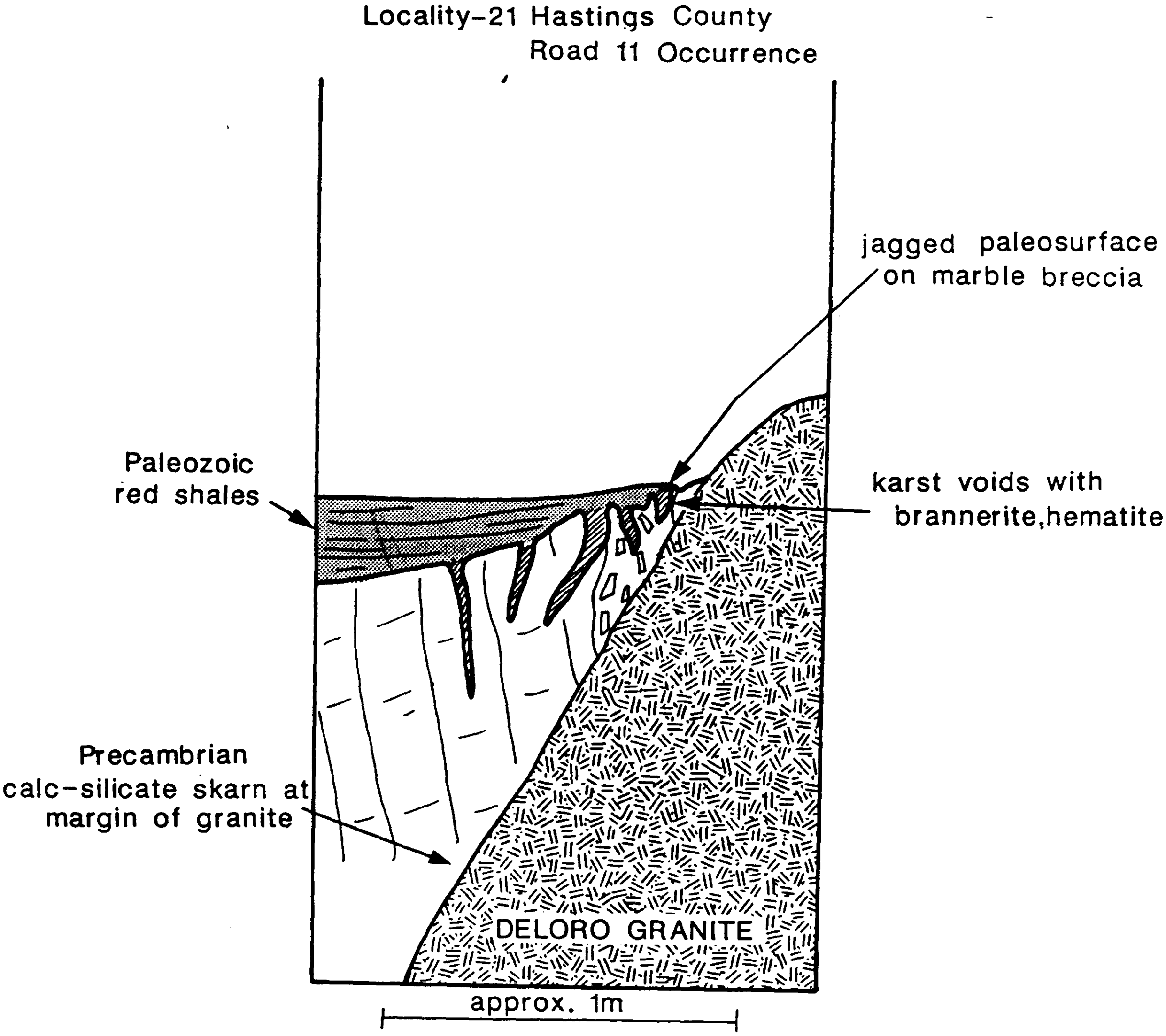


Figure 32: Paleokarst features in calc-silicate skarn and marble breccia at the Precambrian-Paleozoic unconformity at the Hastings County Road 11 occurrence (locality 21).

22. HAZZARDS CORNERS OCCURRENCE

OUTCROP CHARACTERISTICS

Karst structure

Terra rossa

Secondary iron gold enrichment

LOCATION

Hastings county, Madoc township, concession VII, lot 11

UTM: 18T - E303970, N4937250

The occurrence is located immediately west of Hazzards Corners, along Hastings County Road 12, about 6.5 km north of the town of Madoc. Outcrops are also found along the east side of Concession VIII road, opposite the cemetary of the Hazzards Corners church.

DESCRIPTION

At this locality, dolomitic marble occur shows dissolution patterns and redness beneath the unconformity surface along fracture planes and horizontal joint surfaces. These features are most prominent in the uppermost 50 cm of the marble and diminish gradually downward. Fine-grained, sandy residual material cemented with a box-work of hematite, fills fracture planes. Horizontal joint surfaces have been widened to 1 cm by dissolution (Figure 33).

A hand sample from this locality shows grey dolomite, net-veined with calcite containing many voids. This secondary fabric is a sheeting normal to the metamorphic foliation which is vertical. A diffuse hematite stain on the marble, crosscuts the secondary fabric.

Joints and fractures are totally or partly filled with red unconsolited hematite and limonite. Geochemical assays of the infilling oxide show gold contents up to 120 ppb (Geoscience Laboratories, Ontario Geological Survey).

The surface of the marble shows many 1-1.5 mm diameter cylindrical structures, probably boreholes, which pierce the rock vertically or at shallow angles from the surface downward. The basal Paleozoic sandstone crops out 150 m south of this outcrop, and silcrete marks the unconformity only 150 m northward.

INTERPRETATION

Paleogroundwater weathered the marble producing dissolution and inducing the widening of joints and fractures which were filled with a terra-rossa infill derived from decalcification of the Precambrian marbles. Leaching of metals took place in the upper part of the Precambrian beneath the unconformity surface. Subsequent enrichment of gold associated with iron oxide occurred in karstified marble. The unconformity surface was also bored by worm-like organisms.

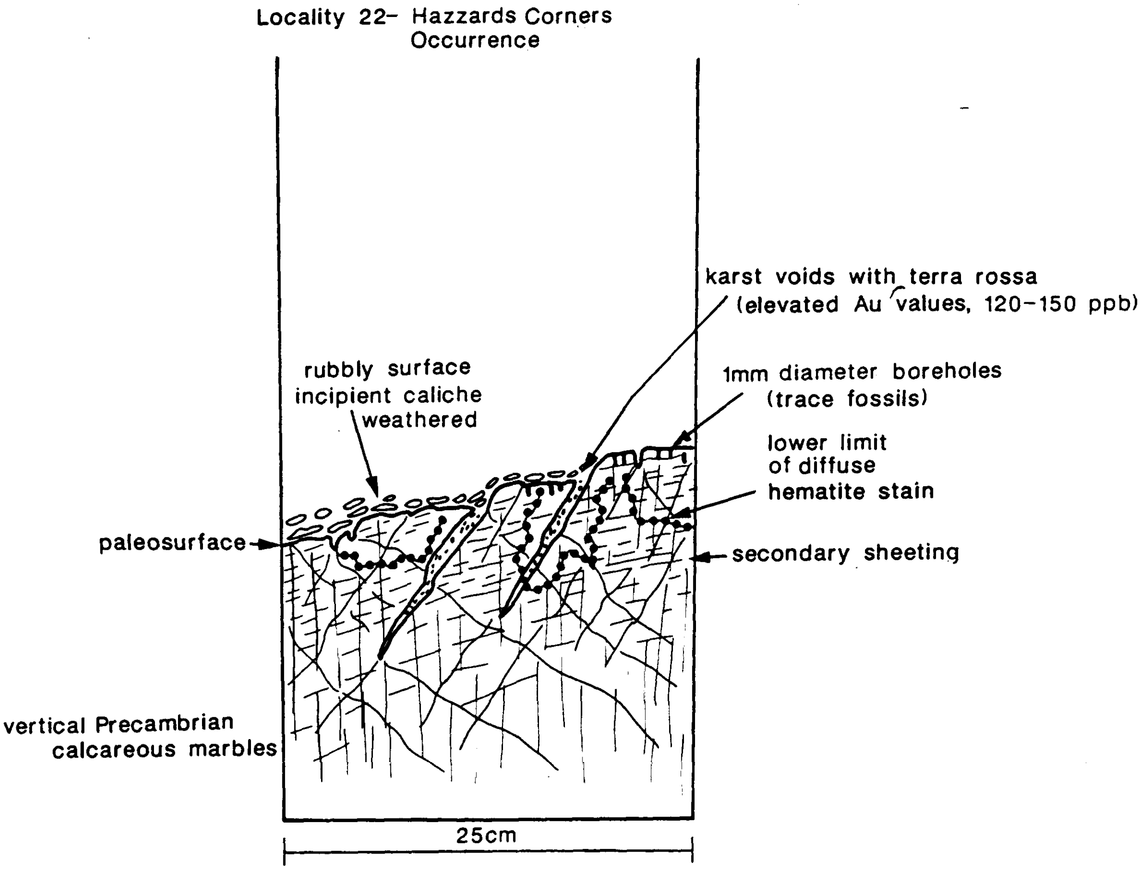


Figure 33: Paleokarst at the Precambrian-Paleozoic unconformity at the Hazzards Corners occurrence (locality 22).

23. RICHARDSON GOLD MINE

OUTCROP CHARACTERISTICS

Karst structure

Secondary gold mineralization

LOCATION

Hastings County, Madoc Township, concession V, lot 18

UTM: 18T - E299645, N4940060

The Richardson gold mine is easily accessible via Highway 62. The mine is situated at the border of the town of Eldorado, about 350 m west of the highway and 50 m north of the railway road.

DESCRIPTION

The Richardson gold mine (1866) in Eldorado was the first gold mine discovered in Ontario and in the Canadian Shield (Vennor 1870, Gibson 1937). The ore deposit occurs at the contact of Precambrian granite and marble. A series of crevices and cavities, up to several metres wide and deep, occur along this contact and in the marbles. The open cavities, found up to 6 metres below the surface, contain brown ferruginous earth and free gold. Gold was also found in marble (Vennor 1870).

INTERPRETATION

The description of the mine by Vennor (1870) suggests karstic weathering. Dissolution cavities formed along lithologic contacts and in the marble. Iron oxide and gold were reconcentrated by supergene processes and deposited in the open spaces created by the karstification. At the Richardson mine the cavities were partially filled with gold-rich ferruginous earth (Vennor 1870). Brannerite was also found in close association with gold at the Richardson mine (Boyle 1979, p.250).

24. 25. 26. BLAKELY, HOLLANDIA AND NOYES MINES

OUTCROP CHARACTERISTICS

Epigenetic mineralization in fractures related to the unconformity

LOCATION

Blakely Mine:

Hastings County, Huntingdon Township, concesion XII, lot 10,

UTM: 18T - E303345, N4927175

Hollandia Mine:

Hastings County, Madoc Township, concession VI, lot A,

UTM: 18T - E298760, N4948780

Noyes Mine:

Hastings County, Huntingdon Township, concession XII, lot 13

UTM: 18T - E305500, N4926700

The Blakely Mine is located near the south shore of the Moira Lake, about 3 km south of the Town of Madoc, and 350 m west of Highway 62 south. Access to the Hollandia mine is by a bush road, east of Highway 62, about 500 m north of the town of Bannockburn. The Noyes mine is situated south of Madoc, 250 m north of Huntingdon concession road 12, about 1.9 km east of Highway 62 south.

DESCRIPTION

Mineralization occurs in near vertical faults that cut both Precambrian and Paleozoic rocks. The most common mineralogical associations are calcite-fluorite-barite and calcite-sulphides. Commonly these ore deposits show open space filling textures, mineral banding, a general lack of visible wall rock alteration, and traces of hydrocarbon, suggesting low temperatures of formation. These characteristics and "the geological setting and location (of the veins) near an intracratonic basin margin, resemble the Mississippi Valley type of deposits" (Carter 1984).

INTERPRETATION

These ore deposits, well accessible and well exposed, represent three samples of the many post-Ordovician vein deposits in the region. The mineralization occurs in post-Ordovician veins, spatially associated with the Precambrian-Paleozoic unconformity. Although the processes occurring at the unconformity surface are not responsible for the formation of these ore deposits, nevertheless they are responsible for the formation of the structures which control the migration of mineralized fluids, and the deposition of minerals.

27. CORDOVA NORTH OCCURRENCE

OUTCROP CHARACTERISTICS

Epigenetic mineralization in veins related to the unconformity

Secondary iron and gold enrichment

LOCATION

Peterborough County, Belmont Township, concession I, lot 21

UTM: 18T - E278190, N4935250

The occurrence lies in the village of Cordova Mines, immediately north of Peterborough County Road 48, opposite the general store.

DESCRIPTION

An exposure of weathered, dark brown gabbro (Cordova Gabbro) crops out on the north side of the road. It is crosscut by mineralized veins. The surface of the gabbro shows exfoliation parallel to the surface and is weathered to a minimum of 10 cm depth. Scattered Paleozoic sandstone and siltstone outcrops occur about 150 m north of this locality. In the weathered gabbro, mineralized veins up to twenty-five centimetres thick, are filled with euhedral white crystals of quartz, and earthy red hematite which coats the faces of the quartz crystals and fills the gap between them (Figure 28). Geochemical assays of this material show gold contents up to 520 ppb (Geoscience Laboratories, Ontario Geological Survey).

INTERPRETATION

Observations from drill logs and from exposures of gabbroic rock beneath the Paleozoic cover at the Blairton iron mine indicate that the weathered Cordova gabbro is similar to weathered gabbro found beneath the Paleozoic. In addition, because of nearby Paleozoic rocks, the authors believe the Precambrian basement outcrops at this locality are the original Precambrian unconformity surface, recently exhumed and showing original paleoweathering features.

The gabbro surface was weathered in pre-Paleozoic time. Paleoweathering is marked by hematite while modern weathering is indicated by a limonitic alteration. Fractures in the gabbro were widened by paleogroundwater. Leaching of minerals from the nearby Precambrian rocks and the veins occurred. Silica, iron and gold were precipitated in open spaces produced by the pre-Paleozoic weathering. Several similar veins of hematite-ochre, with or without quartz, in the basement crop out throughout the study area and are likely of similar origin.

CONVERSION FACTORS FOR MEASUREMENTS IN ONTARIO GEOLOGICAL SURVEY PUBLICATIONS

Conversion from SI to Imperial			**Conversion from Imperial to SI**		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
			AREA		
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
			VOLUME		
1 cm^3	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.308 0	cubic yards	1 cubic yard	0.764 555	m^3
			CAPACITY		
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
			MASS		
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
			CONCENTRATION		
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

▨ UNSUBDIVIDED PALEOZOIC ROCKS

☐ UNSUBDIVIDED PRECAMBRIAN ROCKS

● OUTCROPS SHOWING A CONTACT BETWEEN PRECAMBRIAN AND PALEOZOIC ROCKS

▲ OUTCROPS SHOWING FEATURES OF PALEOWEATHERING AND/OR MINERALISATION RELATED TO THE PRECAMBRIAN–PALEOZOIC UNCONFORMITY

OCCURRENCES:

1. ROAD CUT – HIGHWAY 7 AT OLD MADOC ROAD
2. ROAD CUT – HIGHWAY 7 AT HART'S ROAD
3. CANADA TALC QUARRY
4. HIGHWAY 62 AT RIMINGTON ROAD
5. THE SILO QUARRY AT BARKER ROAD
6. MARMORATON IRON MINE
7. PUBLIC SCHOOL ROAD AT CONCESSION VII ROAD
8. SOUTH OF THE HAZZARDS CORNERS – QUEENSBOROUGH ROAD JUNCTION
9. HIGHWAY 7, 350m EAST OF HART'S ROAD
10. GRENVILLE AGGREGATE – MADOC NORTH, HIGHWAY 7 AT HIGHWAY 62
11. MOIRA LAKE OUTCROP
12. DEER BAY CREEK
13. HAZZARDS CORNERS QUARRY (McCOY QUARRY, STOCKLOSAR, MARBLE QUARRIES)
14. WALLBRIDGE IRON MINE
15. COE IRON MINE (ELDORADO COPPER MINE)
16. FURNACE FALLS OCCURRENCE (NOT SHOWN ON THIS MAP – HALIBURTON COUNTY)
17. MONO GOLD MINE
18. CORDOVA GOLD MINE
19. DIAMOND GOLD MINE
20. BLAIRTON IRON MINE

20'. DUFFERIN IRON MINE

21. HASTINGS COUNTY ROAD 11 OCCURRENCE
22. HAZZARDS CORNERS OCCURRENCE
23. RICHARDSON GOLD MINE
24. BLAKELY MINE
25. HOLLANDIA MINE
26. NOYES MINE
27. CORDOVA NORTH OCCURRENCE