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With 8 figures

Abstract. Skarn mineralization in the southern Gaspé Peninsula is spatially associated with the 225-km-long Acadian Grand Pabos – Restigouche Fault. Skarns are hosted by Ordovician to Silurian limestone of the Matapédia Group. Felsic dikes of calc-alkaline affinity are commonly associated with the skarns. The skarn which occur in the west are Cu-rich, whereas those found in the east are enriched in Zn-Pb-Ag-Au along with Cu. The polymetallic Reboul prospect is described in detail because it combines several of the features typical of skarns along the Grand Pabos – Restigouche Fault. Mineralization and alteration are both lithologically and structurally controlled. Initial skarn and early Cu-Zn-Ag mineralization was emplaced on the southern limb of a major regional Acadian anticline and were confined to a zone of impure limestone. Subsequent pervasive and fracture-controlled retrogressive alteration was accompanied by Cu-Zn-Pb-Ag-(Au) mineralization. Veins of this stage are parallel to the regional cleavage and to fractures related to regional folding and/or induced by deformation along the Grand Pabos Fault. Late mineralization is composed of Ag-Au-Zn-Pb-bearing quartz veins in shears parallel to the Grand Pabos Fault.

Acadian strike-slip tectonics along the Grand Pabos Fault played a major role in the structural setting of the skarn mineralizations and in providing a channelway for ore-bearing fluids. Lead isotopes and fluid inclusions suggest that the fluids may have been derived from hidden Devonian intrusions.

Introduction

At present, the only producing metalliferous mine in the Gaspé Peninsula is the skarn-type porphyry-related Cu-Mo deposit of Mines Gaspé located at Murdochville in the northeastern part of the peninsula (Fig. 1). Various studies of that deposit have been published in recent years including those of Alcock (1982), Shelton & Rye (1982), Shelton (1983) and Procyrshyn (1987). Several authors (Hollister et al., 1974; Hollister, 1978; Williams-Jones, 1982) have suggested the existence of a NE-trending northern Appalachian porphyry-skarn province that stretches from northern Maine to Gaspé. However, little is known about such mineralizations in the southern part of the Gaspé Peninsula, although several types of mineralizations, including skarns and gold-bearing veins, are known to be spatially associated with the composite Grand Pabos –

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Fig. 1. Generalized geology of the Gaspé Peninsula.

Restigouche Fault (Savard, 1985; Fig. 2). This structure represents a major break in the Canadian Appalachians.

In recent years, southern Gaspé Peninsula has been subjected to exploration for a variety of metals. This paper describes and discusses genetic aspects of skarn mineralizations spatially associated with the Grand Pabos – Restigouche Fault, with emphasis on the Reboul prospect, NE of the town of New Richmond (Fig. 2).

**Regional geology and tectonic setting**

The Gaspé Peninsula is a segment of the Appalachian fold belt composed of Paleozoic sedimentary and volcanic rocks, which are divided into three temporal assemblages: (1) a Cambrian to Middle Ordovician assemblage deformed by the Taconic Orogeny during the Middle to Late Ordovician; (2) a Late Ordovician to Middle Devonian assemblage deformed by the Acadian Orogeny during the Middle Devonian; and (3) a post-orogenic undisturbed flat-lying Carboniferous conglomerate (Fig. 1). The rocks deformed by the Taconic Orogeny in the Gaspé Peninsula belong to the
tectono-stratigraphic Humber and Dunnage zones of the northern Appalachians (Williams, 1979). The Upper Ordovician to Middle Devonian rocks are part of a single depositional belt, the Gaspé belt, and are divided into three major Acadian structural zones (Malo & Bourque, in press); from north to south: (1) the Connecticut Valley – Gaspé Synclinorium; (2) the Aroostook – Percé Anticlinorium; and (3) the Chaleurs Bay Synclinorium (Fig. 1).

Igneous intrusive activity of significant proportion occurred only in the northern part of the Gaspé Peninsula where the 370 to 395 Ma McGerrigle plutonic complex intrudes Humber zone rocks. Several stocks and dikes also intrude the post-Taconic cover rocks of the Connecticut Valley – Gaspé Synclinorium (Allcock, 1982; Whalen & Gariépy, 1986; Whalen & Roddick, 1987) (Fig. 1). Smaller felsic dikes and mafic sills, believed to be of Late Silurian to Devonian age, occur throughout the Gaspé belt. The structural trend of the Gaspé belt is dominated by roughly NE-oriented folds, which were produced during dextral transcurrent motion along major E-oriented strike-slip faults during the Acadian Orogeny (Malo & Béland, 1989; Malo & Bourque, in press).

Geologic setting and characteristics of skarns along the Grand Pabos – Restigouche Fault

Skarns and various other mineralization types of southern Gaspé Peninsula are spatially associated with the 225-km-long composite Grand Pabos – Restigouche Fault (Savard, 1985; Malo et al., 1990; Malo & Moritz, 1991; Roy, 1991). This structure is composed of two segments: (1) the E-striking, dextral strike-slip Grand Pabos Fault which transects the Aroostook – Percé Anticlinorium in the east, and (2) the NE-striking oblique-slip Restigouche Fault which borders the Aroostook – Percé Anticlinorium and the Connecticut Valley – Gaspé Synclinorium in the west (Fig. 2). The Aroostook – Percé Anticlinorium includes Upper Ordovician to Lower Silurian sedimentary rocks. In Québec, these rocks are divided into the older terrigenous rocks of the Honorat Group and the younger calcareous sequence of the Matapédia Group (Malo, 1988) (Fig. 2). The latter is subdivided into the older Pabos Formation and the younger White Head Formation.
Nine skarn localities have been delineated along the Grand Pabos – Restigouche Fault (Fig. 2). The skarns are consistently hosted by calcareous rock of the Matapédia Group, more precisely by Ordovician to Silurian limestone of the White Head Formation (Savard, 1985; Malo et al., 1990). No large igneous bodies are exposed nor have been intersected by drilling at any of the skarn localities. However, felsic dikes of calc-alkaline affinity and of granitic to granodioritic composition are common on or in the vicinity of the skarns (Williams-Jones, 1982; Savard, 1985; Malo et al., 1990; Malo & Moritz, 1991; Roy, 1991). The emplacement of the felsic dikes appears to have been controlled structurally as is reflected by the fact that many of them are parallel or perpendicular to the regional foliation.

The skarns along the Grand Pabos – Restigouche Fault display a distinctive geologic, geochemical and mineralogical trend from west to east. The western skarns are Cu-rich, locally with Ag, and the predominant opaque minerals are pyrrhotite, chalcopyrite and pyrite (Williams-Jones, 1982; Savard, 1985). The eastern skarns, on the other hand, are enriched in Pb, Zn, Ag and Au, along with Cu, and contain abundant sphalerite, galena and arsenopyrite (Savard, 1985; Malo et al., 1990; Roy, 1991) (Fig. 2). The western skarns are characterized by a relatively high abundance of felsic dikes and in some places they form swarms, such as at Matapédia (Williams-Jones, 1982). In contrast, felsic dikes are less abundant in the vicinity of the eastern skarns. Finally, chlorite is predominant in the western Cu-dominated skarns, whereas kaolinite is the main clay mineral in the eastern Cu-Pb-Zn-Ag-Au skarns. Smectite was found to be particularly abundant in the barren skarn assemblage of Raudin, the easternmost occurrence discovered to date (Fig. 2).

In general, there is a relationship between the composition of pyroxenes and garnets, and the type of skarn defined on the basis of the dominant metal (Einaudi et al., 1981; Einaudi & Burt, 1982; Meinert, 1983). The composition of pyroxenes and garnets from the western Matapédia and

Fig. 3. Garnet and pyroxene compositions from the eastern skarn at Reboul (dots, this study) and the western skarn at Matapédia (open circles, Williams-Jones, 1982). Compositional fields for garnets and pyroxenes from Zn- and Cu-dominated skarns are from Meinert (1983). Sp: spessartine; Alm: almandine; Gr: grossularite; Ad: andradite; Jo: johannsenite; Di: diopside; Hd: hedenbergite.
the eastern Reboul skarns are plotted in Fig. 3. The pyroxenes are diopsidic, with 15 to 30 mole% hedenbergite, and they fall in the compositional fields typical of Cu- as well as Zn-dominated skarns. The pyroxenes from the western Patapédia skarn tend to be slightly richer in Fe than those from the eastern Reboul skarn.

The garnets show a wider range of compositions compared to the pyroxenes. Garnets in western Patapédia have a composition intermediate between grossularite and andradite and plot in the compositional fields of both Cu- and Zn-dominated skarns. By contrast, garnets from eastern Reboul are grossularite-rich, containing between 23 and 35 mole% andradite. They plot in the compositional field of Zn-dominated skarns, outside of the compositional field of garnets typical of Cu-dominated skarns. In brief, pyroxenes and garnets appear to be more Fe-rich in the western skarns compared to the eastern skarns, with the garnets showing the most contrast. Several factors can affect the composition of garnets and pyroxenes in skarns, including the location within the skarn body, the composition of the protolith, water/rock ratio, temperature and fO2 (Einaudi & Burt, 1982; Meinert, 1987). These variables have not been evaluated critically in the present study and because they may have opposite effects on the resultant pyroxene and garnet compositions, it is not possible, at the present stage of the study, to offer a unique explanation for the observed compositional trends.

The polymetallic skarn at Reboul

Introduction

The Cu-Zn-Pb-Ag-Au prospect at Reboul combines several of the features typical of skarns along the Grand Pabos – Restigouche Fault. It is relatively well exposed and it has been extensively drilled. The Reboul prospect illustrates well the geological setting and the evolutionary processes of skarn formation along the Grand Pabos – Restigouche Fault. Both base-metal-rich skarn and precious-metal-rich vein mineralization are developed at Reboul. They were emplaced during continuous dextral strike-slip motion along the Grand Pabos – Restigouche Fault. The diverse mineral, alteration and vein assemblages are the result of a complex, multi-stage ore-forming process in which early-formed, high-temperature skarn was overprinted by retrogressive alteration and subsequently by lower temperature vein mineralization during late-stage hydrothermal activity.

Local geology

The prospect is hosted by the calcareous rocks of the White Head Formation within a 300-m-wide moderately deformed corridor north of the Grand Pabos Fault (Fig. 4). No extension of the mineralization has been found on the south side of the fault where terrigenous rocks of the Honorat Group occur. The northwestern part of the area is dominated by calcilutite with local interlayers of mudstone, whereas the southeastern part is more heterogeneous with abundant interlayering of argillaceous limestone and calcareous mudstone, and a few beds of calcarenite in calcilutite. A few felsic dikes crop out north of the prospect. These dikes are of calc-alkaline affinity and have a porphyritic texture with sericitized feldspar phenocrysts in a fine grained quartzo-feldspathic matrix.
Fig. 4. Geology of the Reboul prospect (after Landry & Simouneau, 1985; Malo et al., 1990). A-A' and B-B' are the cross-sections shown in Fig. 6.

A 400 × 600 m heterolithic breccia, discordant with respect to the other lithologies, occurs in the western part of the Reboul prospect. The vertical extension of the breccia has not been determined. The breccia is composed of mm- to dm-sized rock fragments supported by a fine grained siliceous, locally carbonatized, rock flour matrix. The angular to subangular clasts consist of calcareous Matapédia Group lithology, terrigenous rocks and volcanic tuff from the stratigraphically underlying Honorat Group, and felsic dike fragments. The characteristics of the heterolithic breccia suggest that it represents a breccia pipe-diатreme system, typical of magmatic activity at depth (cf. Sillitoe, 1985).

Regional NE-trending and SW-plunging folds are accompanied by a penetrative cleavage (Figs. 4, 5A). At Reboul, the skarn mineralization (sensu stricto) is on the southern limb of a major regional anticline. Abundant secondary folds with typically faulted hinges are associated with the regional anticline (Fig. 6A). The fault (sensu stricto) is a 100-m-wide ductile shear zone bordered by a 200-m-wide brittle-ductile deformation envelope grading outward into the calcareous rocks of the White Head Formation which have only been affected by the regional deformation. The Reboul prospect sits astride the contact between the brittle-ductile deformation zone and the domain of regional deformation (Fig. 4).
Alteration

Overprinting relationships indicate a complex prograde-retrograde alteration sequence. Three main paragenetic stages are recognized: metamorphism, metasomatism and retrogression. Metamorphism affects the entire area of the Reboul prospect, whereas metasomatism, which corresponds to the skarn formation stage, is restricted to the eastern and southeastern parts of the prospect (Fig. 4). Retrogressive alteration dominates the alteration sequence and affects metamorphosed, metasomatized and previously unaltered lithologies.

Metamorphic stage: Metamorphism of the various lithologies gave rise to three distinct products: (1) the relatively pure calcilutite in the northwestern part of the prospect was converted into marble; (2) the argillaceous limestone produced a fine grained calcite-dominated rock with needles of tremolite, K-feldspar, plagioclase, quartz, phlogopite, diopside and sphenite, known as calc-silicate marble; and (3) the calcareous mudstone was converted into fine grained calc-silicate hornfels.

Metasomatic stage: Metasomatism, which corresponds to skarn formation, produced grossularite-rich garnet (Fig. 3), vesuvianite, calcite, quartz, K-feldspar, phlogopite and diopside clinopyroxene (Fig. 3). This paragenesis developed at the expense of the calc-silicate marble and hornfels. The skarn assemblage may occur as: (1) thin reaction rims at the contact between marble and calc-silicate hornfels layers; (2) discrete mm-thick and cm-long veins that run across alternating
layers of marble and calc-silicate hornfels; or (3) replacement of the entire metamorphic assemblage obliterating the primary bedding. Skarn formation was both lithologically and structurally controlled. Its development is confined to the southern limb of a regional fold where argillaceous limestone contains abundant interlayers of mudstone and the hinges of secondary folds are typically faulted (Figs. 4, 6A).

Retrogressive stage: Two successive sub-stages can be recognized; both are pervasive and fracture controlled:

1. An initial retrogressive alteration affects the skarn and the hornfels assemblages during which chlorite, sericite, quartz, carbonate, tremolite, sphene, epidote and opaque minerals are formed. Garnet is altered extensively to chlorite, quartz and carbonate. Related to this stage are quartz-chlorite-calcite-opaque mm-sized spots in marble and in skarn, cm- to m-sized veins with the same mineral assemblage, and locally some fluorite in veins.

2. A late retrogressive alteration characterized by an ocher-red assemblage containing calcite, an iron carbonate, hematite and subsidiary quartz. Kaolinite developed at the expense of other phyllosilicates such as chlorite and sericite.
Mineralization

Several mineralizing events with overprinted characteristics can be recognized and correlated with the various stages of alteration, and specific regional and local structural orientations (Fig. 5).

**Copper-zinc-silver:** Pyrrhotite, chalcopyrite, sphalerite and pyrite are the dominant opaque minerals. This assemblage developed at the expense of garnet and it occurs strictly within the skarn areas (Fig. 4). Pyrrhotite was deposited first, and is replaced by chalcopyrite and sphalerite, as well as by marcasite and pyrite. Sphalerite stars in chalcopyrite suggest that chalcopyrite deposition took place above 300°C (Sugaki et al., 1987). No Ag-bearing mineral was observed. However, Ag contents correlate positively with sulphide abundance in this type of mineralization, leading to the conclusion that Ag is contained in one of the sulphides as a solid solution. The Cu-Zn-Ag mineralized zone with the highest grades is located at the southeastern margin of the skarn where it forms a vertical NE-trending sheet, approximately 15 m wide × 75 m long, which extends vertically at least 250 m (Figs. 4, 6A).

**Copper-zinc-lead-silver-(gold):** This assemblage occurs mainly in calcite-quartz veins with minor chlorite, and secondarily, as small disseminations. The corresponding mineral assemblage is dominated by pyrite, chalcopyrite, sphalerite and galena. In the northeastern part of the prospect, arsenopyrite is locally present in veins, where minor silver and bismuth tellurides have also been observed. Freibergite is often associated with this mineral assemblage, particularly in the southwestern part of the prospect; this explains the high Ag content of this mineralization type. Euhedral pyrite and arsenopyrite are the earliest phases, and they are replaced to various degrees by sphalerite, chalcopyrite and galena. Late colomorphous pyrite developed upon the previous minerals. Veins are typically 5 to 50 cm wide and up to several metres long. The veins are commonly subvertical and are controlled either by NW-striking fractures or by NE-trending secondary faults parallel to the regional cleavage (Fig. 5B). The NW-oriented fractures can be interpreted either as AC joints associated with the regional NE-trending folds or as oblique extension fractures related to dextral shear along the E-striking Grand Pabos Fault. The veins cut across all lithologies (i.e. skarn, marble, hornfels, unaltered calcareous rock and the heterolithic breccia), whereas the disseminations are only recognized in skarn and marble. Average metal contents of the veins from the northeastern part are 1.03% Cu, 0.8% Pb, 0.5% Zn, 244 ppm Ag and 1.1 ppm Au; the veins in the southwestern part of the prospect tend to be richer in Pb and Ag (Landry, 1986).

**Silver-gold-zinc-lead:** Sphalerite, pyrite and arsenopyrite dominate this late-stage mineralization. They are accompanied by various quantities of galena, stibnite and sulfosalts, including freibergite, boulangerite, and bournonite. Chalcopyrite is a minor component. Fine, native gold grains occur locally. This mineralization is hosted by 50-cm- to 2-m-wide and metre-long brecciated quartz-carbonate veins. Small fragments of marble and unaltered lithologies are included in these veins. The Ag-Au-Zn-Pb veins are confined to the central part of the prospect, within the brittle-ductile deformation corridor along the Grand Pabos Fault (Fig. 4). They were injected in vertical E-striking dextral shears parallel to the main fault (Fig. 5B) and they resemble breccia dikes (cf. Sillitoe, 1985). They are hosted by marble, skarn and unaltered calcareous rock. The wall rocks are commonly silicified and affected by argillic alteration (illite ± kaolinite). Presently, this type of mineralization constitutes the main ore target at Reboul. One such vein hosted by marble was intersected by drilling and grades 1.8 g/t Au, 44.9 g/t Ag and 1.65% Zn over a length of 2.6 m (Landry, 1986) (Fig. 6B).
Supergene enrichment: Supergene enrichment affects the previous mineralizations, particularly in the eastern and western parts of the prospect. The mineral assemblage includes bornite, chalcocite, digenite, covellite, native copper and native silver.

Microthermometry of fluid inclusions

Preliminary microthermometric fluid inclusion data (Fig. 7) are consistent with the temporal sequence deduced from field and petrographic observations. Early high-temperature and high-salinity primary fluid inclusions ($T_h$ liquid = 450°-460°C; 35–37 wt.% NaCl eq.) were trapped in skarn garnet. They represent either an orthomagmatic fluid or its condensate (Burnham, 1979), or the high saline-low CO$_2$ product resulting from unmixing of a H$_2$O-CO$_2$-salt-bearing metamorphic fluid (Skippen & Trommsdorff, 1986; Williams-Jones & Ferreira, 1989).

A later fluid of lower temperature and lower salinity ($T_h$ liquid = 255°–326°C; 1–9 wt.% NaCl eq.) was trapped in primary inclusions in garnet and in secondary inclusions in sphalerite from the intermediate Cu-Zn-Pb-Ag-(Au) vein stage; in quartz grains from the heterolithic breccia; and in

![Diagram](https://via.placeholder.com/150)

Fig. 7. Microthermometric data of fluid inclusions from the Reboul prospect. The fields of various fluid inclusion types from the Patapédia prospect (Fig. 2) are also shown for comparison.
quartz fragments from a late-stage breccia vein. This lower temperature and lower salinity fluid is most probably the result of the interaction between the early high-salinity and high-temperature fluid with cooler and lower salinity meteoric water as is commonly documented in skarns (Kwak, 1986). This was found to be the case at Mines Gaspé, where Shelton (1983) documented an early high-salinity and high-temperature magmatic fluid that evolved towards a later low-temperature and low-salinity meteoric fluid.

Finally, secondary CO$_2$-bearing vapor-rich and liquid-rich inclusions occur in separate healed fractures in quartz fragments from the late-stage breccia vein ($T_m$ CO$_2$ = -57°C; $T_m$ clathrate = 8.7°-9.4°C; $T_h$ = 337°-350°C). These inclusions have most probably trapped the lower temperature and lower salinity fluid that had incorporated some CO$_2$ released by dissolution of the calcareous host rocks during skarn formation and retrogressive alteration. It is possible that addition of CO$_2$ to the low-salinity and low-temperature fluid triggered unmixing (c.f. Skippen & Trommsdorff, 1986) as evidenced by the coexisting vapor-rich and liquid-rich CO$_2$-bearing inclusions, and could be responsible for some metal deposition.

Preliminary microthermometry on pseudosecondary inclusions in quartz associated with the late Au-Ag-bearing arsenopyrite-pyrite-sphalerite mineralization give homogenization temperatures between 180° and 210°C. This is analogous to late veins in Mines Gaspé where the temperatures gradually decrease from about 350° to 150°C (Shelton, 1983).

**Pb-isotope data**

Limited Pb-isotope data were obtained for galenas from the Robidoux and Reboul prospects (Fig. 2). Although the galena data from both prospects define a linear array in the Pb-Pb plots (Fig. 8), the spread of the data can be entirely accounted for by analytical error. Thus, it indicates that Pb was likely extracted from a homogeneous reservoir. The Pb-isotope composition of the skarn galenas is similar to the initial Pb-isotope compositions of Devonian intrusions from the northern Appalachians determined by Robert et al. (1988) (Fig. 8). Therefore, the Pb in the skarns along the Grand Pabos – Restigouche Fault may have been derived from such Devonian intrusions. However, sources other than Devonian intrusions (e.g. the sedimentary rocks of the Matapédia and Honorat groups) cannot be ruled out.

**Discussion and conclusions**

The skarns in southern Gaspé Peninsula are both lithologically and structurally controlled. First, skarns are confined to the calcareous rocks of the White Head Formation of the Matapédia Group, more precisely to the argillaceous limestone facies, as shown at Reboul (this study) and at Patapédia (Williams-Jones, 1982). Secondly, the tight clustering of skarns along the Grand Pabos – Restigouche Fault suggests a genetic link between the mineralization and that structure. This is well illustrated at the Reboul prospect. Skarn and early Cu-Zn-Ag mineralization were emplaced strike-parallel to a major Acadian regional fold in a zone where the hinges of secondary folds are intensely fractured. Subsequent retrogressive alteration, Cu-Zn-Pb-Ag-(Au) and precious metal veining were controlled by brittle structures associated with the Grand Pabos Fault and are restricted to a zone of moderate deformation bordering the fault. Thus, the structural setting of the skarns and accompanying vein mineralizations suggests that Acadian strike-slip tectonics
along the Grand Pabos – Restigouche Fault played a major role in providing access for the ore-bearing fluids and in preparing the host rocks for the mineralizations.

Williams-Jones (1982) suggested that the western Patapédia prospect was genetically related to Devonian intrusive activity at depth. This probably applies to all the skarns located along the Grand Pabos – Restigouche Fault, and is supported by the lead isotope data from Reboul and Robidoux. The heterolithic breccia at Reboul provides strong additional evidence for some magmatic activity at depth. The chemistry of the felsic dikes associated with the skarn suggests that the related magmatism was of calc-alkaline affinity.

The western and eastern skarns along the Grand Pabos – Restigouche Fault share many similarities, such as the presence of early, high-temperature copper mineralization (this study; Williams-Jones, 1982). Moreover, the comparable fluid inclusion data from the western Patapédia prospect and from the eastern Reboul prospect (Fig. 7) indicate that similar fluids, of both
magmatic and meteoric origin, were probably involved in the genesis of the various skarns along the Grand Pabos – Restigouche Fault, which are akin to the skarn at Mines Gaspé (Shelton, 1983). However, the Cu-rich nature of the western skarns together with the high abundance of felsic dikes are in striking contrast with the eastern skarns which are enriched in Zn-Pb-Ag-Au and where felsic dikes are less abundant. Thus, if one adopts classical skarn models (Einaudi et al., 1981; Einaudi, 1982), these dissimilarities signify that the western skarns were probably developed much closer to an intrusion, possibly in an analogous setting to that of Mines Gaspé (Allcock, 1982), whereas the eastern skarns are more distal to such an igneous body.

Finally, the spatial association of skarns with a major regional fault in southern Gaspé Peninsula and the complex, multi-stage genesis of the mineralizations such as at Reboulow, where initial skarn is subsequently overprinted by extensive retrogressive alteration and late precious-metal-bearing veins, are similar to skarns with associated vein mineralization found elsewhere, such as in Indonesia (Beddoe-Stephens et al., 1987), Mexico (Rubin & Kyle, 1988) and Australia (Ewers & Sun, 1989).

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