Major, trace element and stable isotope geochemistry of synorogenic breccia bodies, Ellsworth Mountains, Antarctica

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Abstract Cambrian carbonates in the Heritage Range of the Ellsworth Mountains, West Antarctica host a series of carbonate-rich breccia bodies that formed contemporaneously with the Permian Gondwanide orogen. The breccia bodies had a three-stage genesis, with the older breccias containing Cambrian limestone (and marble) clasts supported by calcite, whereas the younger breccias are nearly clast-free and composed entirely of matrix calcite. Breccia clasts, calcite matrix and detrital matrix samples were analyzed using x-ray fluorescence (major and trace elements), x-ray diffraction, and stable isotopes (C, O) and suggest that the breccias formed as part of a closed geochemical system, at considerable depth, within the Cambrian limestone host as the Ellsworth Mountains deformed into a fold-and-thrust belt along the margin of Gondwana.

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Introduction

Breccia formation in thin-skinned thrust belts is usually associated with displacement on fault surfaces and is not lithology-dependent. The breccias in the southern Heritage Range of the Ellsworth Mountains, West Antarctica are not planar, fault-related breccias but rather a three-phase progression of breccia body formation contained within the middle Cambrian Minaret Fm. limestones. The field relations of the breccias have been described at length by Sporli et al. (1992) and are reviewed here briefly. The oldest breccia bodies are large, irregularly shaped, randomly oriented and rich in limestone clasts supported in a calcite matrix. The intermediate breccias are smaller, more cylindrical in shape, tend to have margins that are cleavage or bedding planes and are more calcite matrix-rich (Fig. 1a). The youngest breccias are mostly cylindrical, cross-cut both earlier breccia types and are clast-free (Fig 1b). Where clasts are present they are locally-derived Minaret Fm. limestones and marbles (some are mylonitic), which contain the Gondwanide axial-planar cleavage; some are bedded. Many breccia margins appear leached and discolored. Detrital deposits are present in the breccias, some appearing as small channel deposits, often with local cross-bedding. Some breccias are contemporaneous and are cross-cut by Gondwanide thrust faults, and are offset toward the northeast on southwest-dipping thrusts. Internally, all the calcite, clasts and younger matrix, contain two sets of mechanical twins indicating preservation of some tectoni c deformation. In outcrop, it appears that the entire breccia system involves nothing but calcite and dolomite. This effort was intended to characterize the origin of the breccias by analyzing their geochemistry, an effort limited by a small sample suite.

Figure 1. (a): The 'type' breccia body in the Independence Hills is a vertical cylinder (100 m high) with internal layering and with margins parallel to the sub-vertical axial-planar cleavage. Note horizontal, cylindrical breccia body on right; both cross-cut folds in the Cambrian Minaret Fm. (b; lower) A type 2 breccia cut by a cylindrical, matrix-free breccia pipe (diameter= 3 meters).

Methods

Samples were observed petrographically, and powders were prepared for X-ray diffraction (5 samples, Macalester College), X-ray fluorescence (5 samples,

Table 1 Major elements (wt %); trace elements (ppm) of breccia components

Major Elements Sample	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	BaO	Cr2O3	Ce	Co	Cu
LS Clast	1.10	0.01	0.19	0.14	0.01	0.27	51.73	0.00	0.06	0.01	int	0	1	5	50
Red matrix	5.00	0.06	1.40	6.63	0.04	0.23	45.45	0.00	0.18	0.08	int	0	67	4	40
Calcite Matrix	0.07	0.01	0.09	0.03	0.00	0.02	51.75	0.00	0.03	0.00	int	0	20	6	44
White Matrix	5.02	0.06	1.17	0.27	0.01	0.30	50.18	0.00	0.27	0.02	int	0	35	6	28
Red Matrix	2.41	0.04	1.16	1.40	0.05	0.17	47.29	0.05	0.10	0.02	int	0	45	2	38

	Ni	Sc	Ga	Nb	Pb	Rb	Sr	Th	U	Zr	V	Zn	LOI	Total
LS Clast	6	10	0	2	6	1	213	0	0	23	9	8	42.76	96.29
Red Matrix	34	9	1	4	22	11	46	8	0	38	19	121	37.44	96.54
Cacite Matrix	5	11	0	2	4	0	16	0	0	23	2	20	42.86	94.87
White Matrix	8	8	1	4	19	10	54	6	0	36	15	93	40.74	98.07
Red Matrix	12	13	0	3	7	5	71	0	0	29	14	56	41.62	94.34

McGill University), and stable isotope (6 samples, University of Minnesota) analysis. Samples include the Minaret clasts, breccia calcite matrix and breccia detrial units.

Results

Thin section and X-ray analysis of the various breccia materials identified calcite with minor amounts of dolomite (1%), quartz (1%) and hematite (4%, red matrix only). All the samples had considerable loss on ignition (LOI; 37-42%), and concentrations of major and trace elements that are consistent, broadly, with a marine limestone XRF analysis (Table 1). Stable isotope (O, C) analyses revealed a consistent signature for the Minaret limestones, but the breccia matrix calcite is depleted: breccia matrix calcite (7.48, 7.69, 5.87 δ^{18}O (SMOW) and 0.24, -0.57, -4.14 δ^{13}C (PDB); Minaret limestone 18.81 δ^{18}O (SMOW), 3.88 δ^{13}C (PDB), oolitic Minaret limestone 21.55 δ^{18}O (SMOW), 0.75 δ^{13}C (PDB), mylonitic Minaret marble 21.60 δ^{18}O (SMOW), 0.77 δ^{13}C (PDB).

Discussion and conclusions

The 'type' breccia body shape (Fig. 1a) suggests an igneous origin for these carbonate-rich, carbonate-hosted structures. Carbonatites are usually associated with rift tectonic settings, and are complex alkaline melts with mineral assemblages that include calcite, dolomite, and ankerite, as carbonate phases, and clinopyroxene, biotite, apatite and magnetite, and have fairly distinctive major and trace element concentrations. These breccias do not contain any silicate minerals and, for instance, have concentrations of $Ti0_2$, MgO and P_2O_5 that are ~10, ~60 and ~ 50 times lower than the average carbonatite. Trace elements (e.g., Th, Y, Ce, Zr) in the breccias are 10-75 times lower than in the average carbonatite. Both the major and trace element concentrations are comparable within the range of limestone compositions. Carbonatite calcites have δ^{18}O (SMOW) and δ^{13}C (PDB) values of 6.6-7.6 and -2 to -8, respectively, whereas marine limestones are ~31 and 0. The Minaret limestones are depleted but in the range of limestones. The matrix calcite is very depleted and suggestive of a hydrothermal or carbonatitic source.

Field and cross-cutting relations support a synorogenic origin for the breccia bodies in the late Permian. The breccia geochemistry suggests a closed carbonate-calcite system existed during the Gondwanide deformation and that hydrothermal fluids flowed within the closed Minaret Fm. portion of the thick Ellsworth section (Buggisch and Webers, 1992) dissolving and reprecipitating calcite in a continuum of three breccia phases. There are no void spaces in any of the breccia bodies so this was not an open system (i.e., karst), and breccia matrix calcite fluid inclusion homogenization temperatures (160°; Sporli et al., 1992) support a considerable depth for these rocks at the time of breccia formation. The Ellsworth Mountains were uplifted in the Cretaceous, exposing the breccias, based on the fission tracks studies of Fitzgerald and Stump (1991).

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[An updated bibliography on the Ellsworth Mountains is maintained at: www.macalester.edu/~craddock/paper/EWMRefs.doc].