Timing of Iron Oxide-Copper-Gold (IOCG) Mineralization and Alteration along the Cobequid-Chedabucto Fault Zone

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Introduction

A fundamental component in developing any model for mineral deposit genesis is an appreciation of the relative or absolute timing of mineralization. Although significant exploration projects have been conducted and are currently under way in search of iron oxide-copper-gold (IOCG) deposits in the Cobequid-Chedabucto Fault Zone (CCFZ) of northern mainland Nova Scotia (e.g. Setterfield, 2005; Belperio, 2007), mineralization has only been directly dated at the Copper Lake Cu-Au deposit where a ca. 325 Ma Re-Os age was obtained for hydrothermal pyrite associated with chalcopyrite and bornite (Kontak *et al.,* 2008). Due to the regional distribution and spectrum of IOCG-style deposits, occurrences and geochemical anomalies found along the CCFZ (e.g. Fe, Cu, Au, Ba, Co and Ni), and the fact that most deposits are not amenable to conventional radiometric age dating, an indirect assessment of the relative timing of mineralization is required. As IOCG deposits are universally contained within breccias, associated with large hydrothermal alteration haloes and, to varying degrees, spatially and/or genetically related to coeval magmatism (Hitzman, 2000), a compilation of available ages for magmatism, deformation, metamorphism and hydrothermal alteration along the CCFZ has been undertaken. The aim of the study is to assess the most likely time interval for IOCG-style mineralization along the fault zone.

Mineral Deposits, Prospects, Occurrences and Geochemical Anomalies

Numerous mineral deposits, occurrences, geochemical anomalies and alteration zones are found along the CCFZ, which are now collectively considered to be indicative of IOCG-style deposits (O'Reilly, 1996; O'Reilly, personal communication). Notable hydrothermal mineral deposits, prospects and occurrences from west to east include: (1) the Bass River magnetite prospect, (2) the Londonderry iron deposits, (3) the Brookfield barite deposit, (4) the Mount Thom Cu-Co-Au prospect, (5) the Bridgeville iron deposits, (6) the College Grant Cu deposit, (7) the Copper Lake Cu-Au deposit and (8) the South Manchester iron deposit (Fig. 1). Geochemical anomalies in stream sediment heavy mineral separates, particularly for Cu, Co and Ni, are also very prominent along the CCFZ (O'Reilly, personal communication).

Late Devonian-Carboniferous Magmatism along the CCFZ

The most prominent and voluminous magmatic event recognized along the CCFZ is ca. 365-350 Ma (Doig *et al.,* 1996; Dunning *et al.,* 2004). This event is well-documented in the Cobequid Highlands where it is represented by a bi-modal suite of mafic-felsic plutons and volcanics (Figs. 1 and 2). Shallow emplacement of the plutons, the abundance of sills, and coincident U-Pb zircon and Ar-Ar hornblende and biotite crystallization ages suggest rapid cooling of magmas (Pe-Piper *et al.,* 2004). These data are in agreement with structural observations and stratigraphic information suggesting that crustal extension was contemporaneous with magmatism, and with the initiation of widespread terrestrial clastic sedimentation in the Maritimes Basin (e.g. Horton Group deposition; Fig. 2).

Carboniferous magmatism has yet to be dated radiometrically within the CCFZ, but it has been

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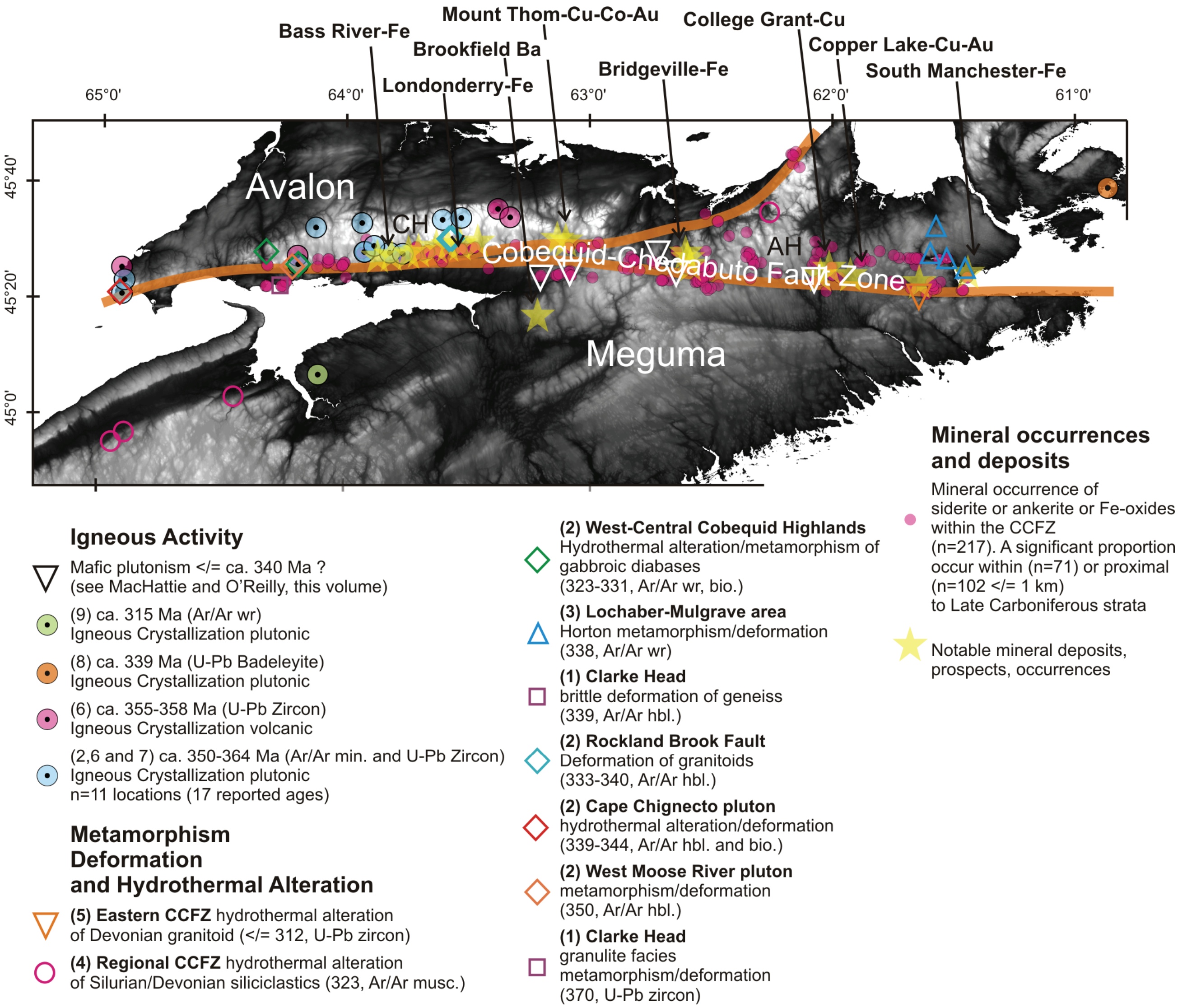

Figure 1. Digitial elevation map of the Cobequid-Cedabucto Fault Zone (CCFZ), which forms the Avalon-Meguma terrane boundary in mainland Nova Scotia. Displayed are the locations of geochronological and geochemical samples (also see Fig. 2), Fe-carbonate and -oxide occurrences, and notable prospects and deposits of Fe, Cu, Au, Ba, Co, and Ni discussed in the text. CH Cobequid Highlands, AH Antigonish Highlands. Heavy lines denote prominent splays of the CCFZ. References for geochronology include: (1) Gibbons *et al.* (1996); (2) Pe-Piper *et al.* (2004); (3) Reynolds *et al.* (2004); (4) Murphy and Collins (2007); (5) MacHattie *et al.* (in preparation); (6) Dunning *et al.* (2004); (7) Doig *et al.* (1996); (8) Barr *et al.* (1994); (9) Kontak *et al.* (2000); (10) Giles and Utting (1999); (11) Giles (2008).

documented peripheral to the fault zone (Figs. 1 and 2) and elsewhere in the Maritimes Basin. A ca. 339 Ma gabbro has been dated from the St. Peter's area on Cape Breton Island (Barr *et al.,* 1994), and a ca. 315 Ma age has been reported for a dyke cutting the Horton Group in the Cheverie area, south of the Minas Basin (Kontak *et al.*, 2000). Unnamed late Tournasian-Viséan basalts (ca. 340 Ma) have been recognized near the top of the Horton Group in drill core from the Gulf of St. Lawerence (Giles and Utting, 1999), and new palynological constraints indicate that basalts found on the Magdalen Islands are ca. 330 Ma (Giles, 2008).

Although currently undated, new geochemical sampling of gabbroic rocks suggests that Carboniferous mafic magmatism may in fact be widespread within the CCFZ (MacHattie and O'Reilly, 2009). Five gabbros located along a ~100 km segment of the central CCFZ (Fig. 1) have incompatible trace element signatures that are remarkably similar to the dated ca. 340-315 Ma mafic magmas described above (see MacHattie and O'Reilly, 2009). Importantly, these newly sampled gabbros intrude strata of the Windsor-Cumberland groups and their geochemical signatures are distinct from Jurassic basalts, features consistent with a Late Carboniferous-Permian(?) age.

Metamorphism, Deformation and Hydrothermal Alteration

Radiometric ages for metamorphism, deformation, and hydrothermal alteration along the CCFZ in Nova Scotia range between ca. 370 and 310 Ma (Figs. 1 and 2, and references therein). Ages for some of the earliest tectonic activity along the CCFZ are currently limited to its western segment where high-grade, ca. 370 Ma, granulite-facies metamorphism and deformation is recognized at Clarke Head (Gibbons *et al.,* 1996) and ca. 350 Ma deformation is recorded within the West Moose River Pluton (Pe-Piper *et al.,* 2004).

Deformation, metamorphism and hydrothermal alteration younger than ca. 340 Ma is, however, very well-recognized along the CCFZ (Fig. 2). Amphibole veins in the Clarke Head granulite record ca. 339 Ma brittle deformation (Gibbons *et al.,* 1996). Deformation and hydrothermal alteration of the Cape Chignecto Pluton occurred between ca. 339 and 344 Ma (Pe-Piper *et al.,* 2004). Movement on the Rockland Brook Fault occurred ca. 340 Ma (Pe-Piper *et al.,* 2004), and metamorphism and deformation of Horton Group at ca. 338 Ma is recognized in the Lochaber-Mulgrave area (Reynolds *et al.,* 2004). In addition, regional fluid flow along the CCFZ is recognized by regionally distributed ca. 323 Ma muscovites found within Silurian-Devonian siliciclastics peripheral to the CCFZ (Murphy and Collins, 2007), and coincident with hydrothermal alteration of a diabase dyke in the West Moose River pluton at ca. 323 Ma (Pe-Piper *et al.,* 2004).

Some of the youngest fault movements include megabreccia formation at Clarke Head (Mabou Group-granulite mélange), which is constrained to a maximum age of ca. 312-315 Ma as it is unconfomably overlain by the lower Cumberland Group (Gibbons *et al.,* 1996). Megabreccia formation may have been coincident with renewed uplift of the Cobequid Highlands as its northern margin is also unconformably overlain, in part, by the lower Cumberland Group. A new ca. 312 Ma age (U-Pb zircon) has recently been documented in a ca. 380 Ma, hydrothermally altered granite along the western end of the CCFZ (Fig. 3; MacHattie *et al.,* in preparation), an age interpreted to record the hydrothermal alteration and brecciation of the granite.

Timing of Siderite-Ankerite-Fe-oxide Vein Formation

Iron carbonate- and iron oxide-bearing vein and breccia systems are the principal carriers of hydrothermal mineral deposits of IOCG-affinity in the CCFZ. Therefore, if the relative age of the host rocks can be determined a semi-quantitative assessment of the timing of IOCG-style mineralization in the CCFZ can be obtained. Although it is currently not known if formation of the widespread siderite-ankerite-Fe-oxide (±Cu±Au±Co±Ba) veins along the CCFZ record a protracted (e.g. formed over tens of Ma) or a relatively short-lived event (e.g. ≤ 10 Ma or less), a significant portion of these veins occur within (n=71/217) or are proximal to (n= 102/217 ≤ 1 km) Upper Carboniferous strata (Fig. 1). This indicates that many are certainly ≤ ca. 330 Ma in age.

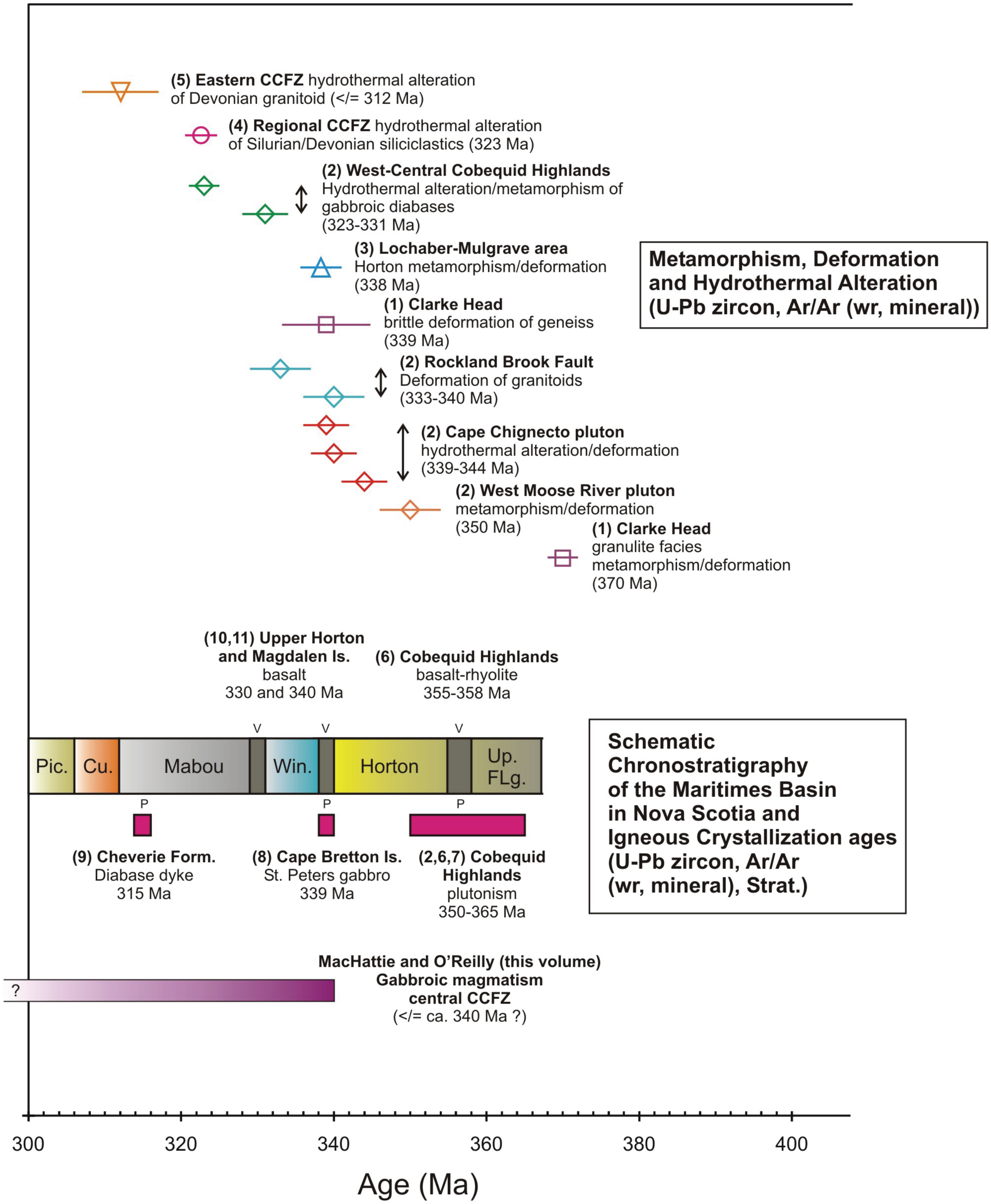

Figure 2. Late Devonian-Carboniferous ages for magmatism, metamorphism, deformation and hydrothermal alteration along the CCFZ. A schematic chronostratigraphy for the Maritimes Basin in Nova Scotia is also shown.

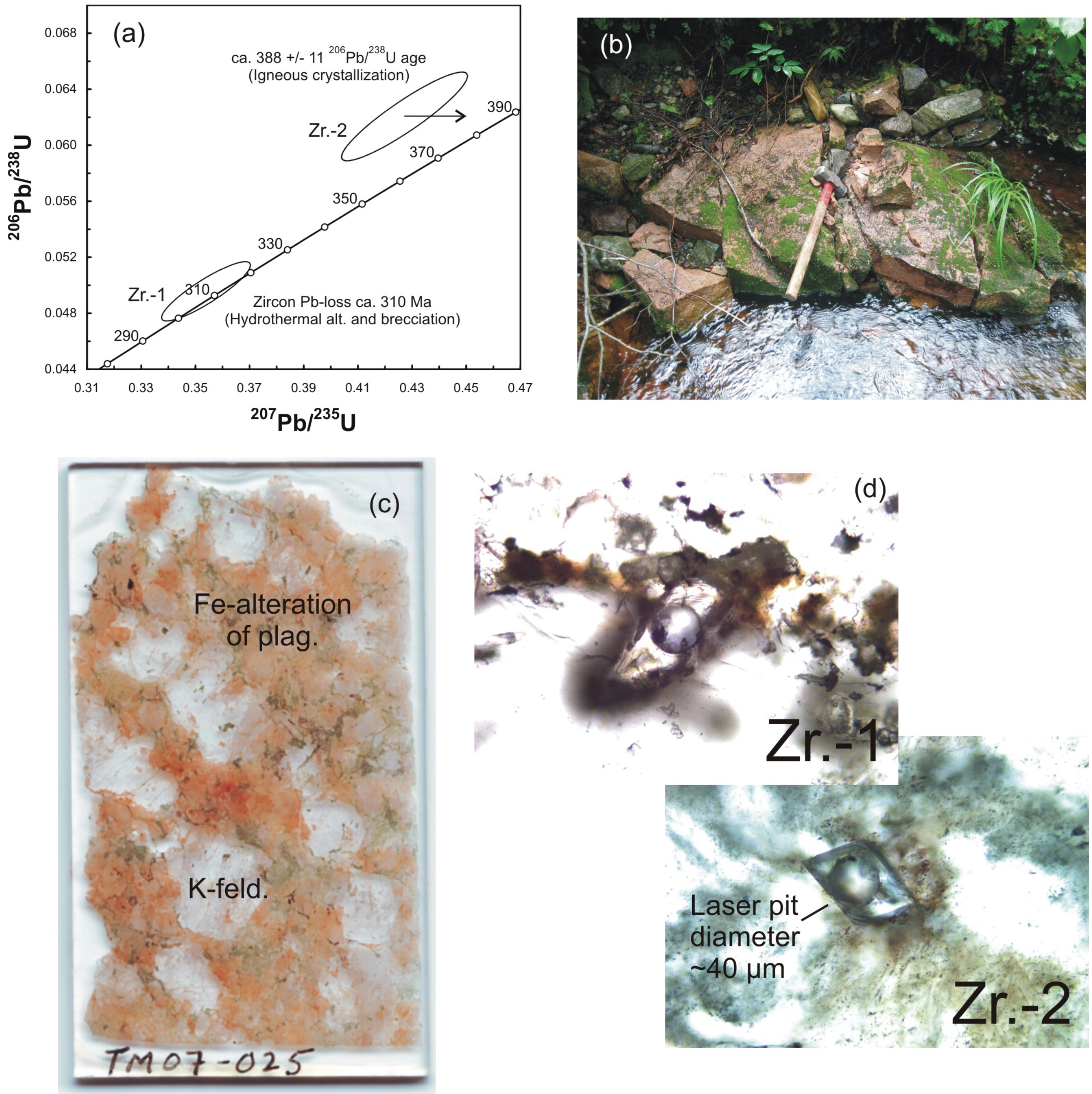

Figure 3. (a) U-Pb concordia plot for two *in situ* zircon analyses (laser ablation) from garnet-muscovite-bearing granitoid TM07-025 (MacHattie *et al.*, in preparation). Zircon 2 (diamond-shaped, euhedral, clear and colourless) is interpreted to record the crystallization age of the granitoid (ca. 380 Ma) and is consistent with previous geochronology, mapping, and geochemistry (Hill, 1991). Zircon 1 is interpreted to have experienced hydrothermal alteration (Pb-loss) at ca. 310 Ma. (b) Outcrop photo of graniotid TM07-025 (hammer is 50 cm long). (c) Thin section image of granitoid TM07-025, note the intense Fe-alteration of plagioclase. (d) Photomicrographs of the zircon crystals analyzed from granitoid TM07-025 (ablation pits are ~40 µm in diameter). Detailed analytical methods for *in situ* petrographic thin section U-Pb dating of zircon can be found in Simonetti *et al.* (2006).

Conclusions

There is widespread evidence (>300 km of strike length) for metamorphism, deformation and hydrothermal alteration along the CCFZ between ca. 340 and 310 Ma. This age range is coincident with the new ca. 323 Ma Re-Os age obtained for the Copper Lake Cu-Au deposit and many of the siderite-ankerite-Fe-oxide vein systems along the CCFZ that possess an IOCG affinity. These data suggest that IOCG-style mineralization in the CCFZ is Late Carboniferous in age. The recognition that gabbros of this age may be widespread within the CCFZ (MacHattie and O'Reilly, 2009) supports this interpretation.

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