Isotopic age constraints from electron microprobe U-Th-Pb dates, using a three-dimensional concordia diagram

YVETTE D. KUIPER

Department of Geology, University of New Brunswick, Fredericton, New Brunswick E3B 5A3, Canada

ABSTRACT

Using a three-dimensional U-Th-Pb concordia diagram, electron microprobe (EMP) U-Th-Pb analyses are shown to yield isotopic age constraints on isotopically concordant and discordant data that have not been recognized previously. The three-dimensional U-Th-Pb concordia diagram is discussed. It is demonstrated that a date obtained from an EMP analysis is as old as or younger than the \(^{207}\text{Pb}^{/}/235\text{U}\) and \(^{207}\text{Pb}^{/}/206\text{Pb}\) ages, and as old as or older than the \(^{208}\text{Pb}^{/}/232\text{Th}\) age. EMP analyses always yield a minimum age for the oldest Pb component.

INTRODUCTION

The technique of EMP U-Th-Pb dating of minerals that are rich in Th, U, and radiogenic Pb, especially monazite, has been developed over the past decade (e.g., Suzuki and Adachi 1991; Montel et al. 1996; Williams and Jercinovic 2002, and references therein) and is now widely used. Because, in the EMP analysis, element concentrations rather than isotopes are measured, three assumptions need to be made: (1) no common Pb is present, (2) the system has remained closed (i.e., no Pb loss), and (3) the analyzed volume is homogeneous; therefore, isotopic data would yield concordant ages (Montel et al. 1996; Williams and Jercinovic 2002). The first assumption is thought to be reasonable, because the common Pb concentration in monazite and other minerals used for EMP dating is much less than the detection limit, and less than the measurement error, for Pb on the microprobe (cf., Parrish 1990; Heaman and Parrish 1991; Suzuki and Adachi 1991; Montel et al. 1996; French et al. 2002). The second assumption has been considered reasonable, because the EMP spots are as small as 2 \(\mu\)m, and EMP element maps may be utilized to identify compositional domains that may correspond with possible age domains (Williams et al. 1999; Williams and Jercinovic 2002). Therefore, the chance that two age domains overlap within the analyzed volume is small. Furthermore, for monazite, the mineral most commonly dated by EMP methods (cf., Cocherie and Albarede 2001; Williams and Jercinovic 2002), Pb loss by volume diffusion is negligible, as has been demonstrated by means of natural examples (Braun et al. 1998; Cocherie et al. 1998; Crowley and Ghent 1999; Cocherie and Albarede 2001). Experimental work confirms that, even at high temperatures, volume diffusion is very slow (Smith and Giletti 1997; Seydoux-Guillaume et al. 2002; Cherniak et al. 2004). This may be partly a result of the lack of metamictization in monazite, which Seydoux-Guillaume et al. (2002b) attributed to low temperature annealing.

However, the possibility of Pb loss must be considered with respect to its effect on an EMP age for two reasons. (1) Monazite can lose Pb by alteration (Hawkins and Bowring 1997; Braun et al. 1998; Poitrasson et al. 2000) or partial dissolution and precipitation (Teufel and Heinrich 1996; Hawkins and Bowring 1997; Ayers et al. 1999; Crowley and Ghent 1999; Poitrasson et al. 2000). In some of the latter papers, Pb loss is said to be a result of “recrystallization.” However, in those cases, “recrystallization” is used to indicate dissolution and precipitation, and not deformation-induced recrystallization within strained crystals or aggregates as defined by Hobbs et al. (1976, p. 107–114). Lead loss in monazite as a result of deformation-induced recrystallization is not recorded in the literature. (2) The EMP dating method is also used for other minerals such as uraninite (Kucha et al. 1986; Bowles 1990), zircon (Suzuki and Adachi 1991; Geisler and Schleicher 2000; Asami et al. 2002), xenotime (Suzuki and Adachi 1991; Asami et al. 2002) and baddeleyite (French et al. 2002), which may be more susceptible to Pb loss (e.g., Heaman and Parrish 1991; Mezger and Krogstad 1997).

Additionally, it is possible that two age domains within a mineral are probed simultaneously (e.g., Seydoux-Guillaume et al. 2003), in which case the assumption that the analyzed volume is homogeneous (see above) obviously is invalid. Probing of two age domains may occur if the EMP analytical volume intersects a second age domain at depth, or if the age domains are not coincident with the compositional domains (e.g., Catlos et al. 2002), or if small grains with small age domains are analyzed.

If Pb loss occurred, then the Pb/(Th + U) ratio is lowered with respect to the original ratio. If more than one age domain is probed by the microprobe beam, then the total Pb/(Th + U) ratio is lower than that of the oldest age domain. Either case results in isotopic discordance, which means that the \(^{207}\text{Pb}^{/}/235\text{U}\), \(^{208}\text{Pb}^{/}/206\text{Pb}\), and \(^{208}\text{Pb}^{/}/232\text{Th}\) ratios yield different ages (Wetherill 1956; Tilton 1960). Therefore, an EMP analysis of an isotopically discordant mineral domain always has a lower Pb/(Th + U) ratio and, therefore, yields a younger apparent age than the age of oldest Pb component, and isotopic discordance cannot be recognized by EMP methods. More specifically, as shown in