U-Pb analysis of zircons:
the Lochnagar Granite, NE Scotland

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Introduction

The U-Th-Pb age dating technique is a powerful and precise method to date crystallisation ages and metamorphic events. The mineral zircon ($ZrSiO_4$) is particularly suitable for age dating as it often contains relatively large amounts of U, Th and Pb and is extremely robust remaining essentially unaffected by subsequent geological events. *In situ* microbeam techniques enable the study of individual growth zones (Fig.1) in zircons, which can reveal vital information about the growth sequence and evolution of the mineral and its host rocks.

This study on the Lochnagar Granite combines O-isotope, trace element, Lu-Hf and U-Th-Pb data to investigate the origins and evolution of selected Scottish late-Caledonian granites and their source rocks.
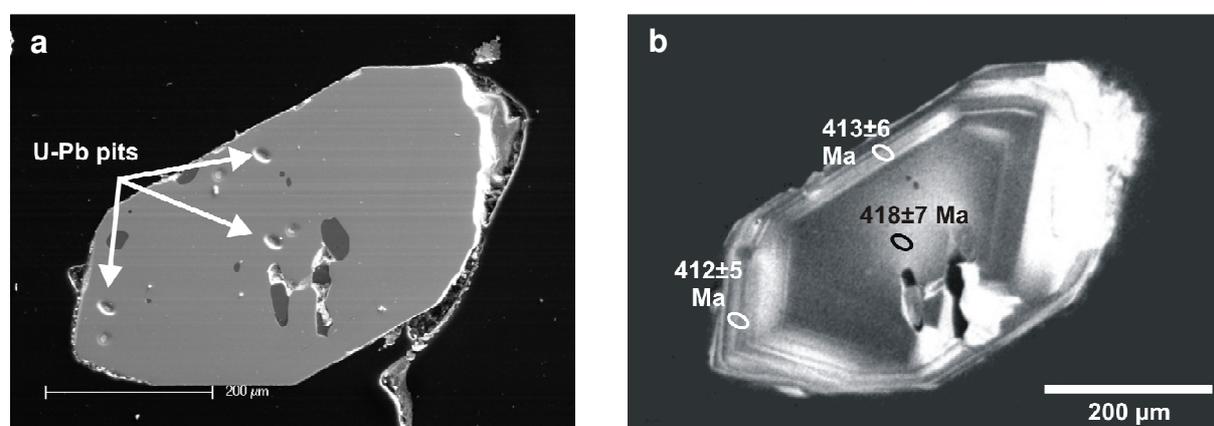
Fig.1: Secondary electron (SE) (a) and cathodoluminescence (CL) (b) images of the same zircon grain. SE image shows location and size of U-Pb analysis pits. CL image diplays targeted zones within the zircon and determined ages.

U-Th-Pb method

The U-Th-Pb method is based on the radioactive decay of U and Th to stable isotopes of Pb. U naturally occurs as radiogenic isotopes ^{238}U, ^{235}U and ^{234}U and Th primarily as radiogenic ^{232}Th. Pb exists as radiogenic isotopes ^{206}Pb, ^{207}Pb, ^{208}Pb and non-radiogenic isotope ^{204}Pb. ^{204}Pb is also referred to as common Pb and often represents contamination on the surface of the sample. Each of the U and Th isotopes reflects the parent of a chain of radiogenic daughter isotopes, which all decay to a stable isotope of Pb, i.e ^{238}U decays to ^{206}Pb, ^{235}U to ^{207}Pb and ^{232}Th to ^{208}Pb [1].

The U, Th and Pb concentrations in the Earth's mantle are very low. During partial melting of the mantle U, Th and Pb preferentially get incorporated into the liquid phase. This leads to enrichment of U, Th and Pb in the crust in comparison to the mantle. In common rock-forming minerals the concentrations of U and Th are very low. However, high abundances can be found in accessory minerals, e.g. zircon and monazite where U and Th are either a major constituent of the mineral or substitute for other elements [1].

Zircon is commonly used for U-Th-Pb geochronology as it is the most abundant accessory mineral in most igneous and metamorphic rocks. It has the advantage of being chemically and mechanically extremely robust and it readily incorporates U and Th but not Pb. Therefore, at the time of crystallisation virtually no Pb is present in the zircon. After crystallisation is completed the radioactive decay of U and Th begins to produce Pb. By

measuring the concentrations of U, Th and Pb in the zircon sample and determining the isotopic composition of Pb the age of the zircon can be calculated. In addition, the U and Th abundances and the Th/U ratio deliver important information about the zircons' host rock. The ability to read this geochemical record makes zircon ideal for studying the evolution of the crust [1].

SIMS technique

U-Th-Pb analyses were made using the Cameca ims1270. The peaks measured were: HfO, ^{204}Pb, ^{206}Pb, ^{207}Pb, ^{208}Pb, Zr_2O_2 (212), ^{238}U, ThO, UO (254), UO_2 (270). Fig.2 shows that Zr as well as Hf peaks close to the U and Pb peaks can cause interferences. However, the high mass resolution of the ion probe allows identification of the individual peaks. Unsuccessful separation of the peaks would lead to incorrectness of the data.

O_2 flooding is employed to enhance Pb ion yield. Secondary ions are collected at an accelerating voltage of 10kV, detected on a single ion-counting electron multiplier with a fixed dead-time of 51 nanoseconds.

Data reduction involves corrections made based on Pb/U vs UO_2/UO, with Pb and U concentrations based on U/Zr_2O_2 vs UO_2/UO. Th/U ratios are calculated based on zircon standard 91500. Corrections are made for dead time, detector background and common Pb.
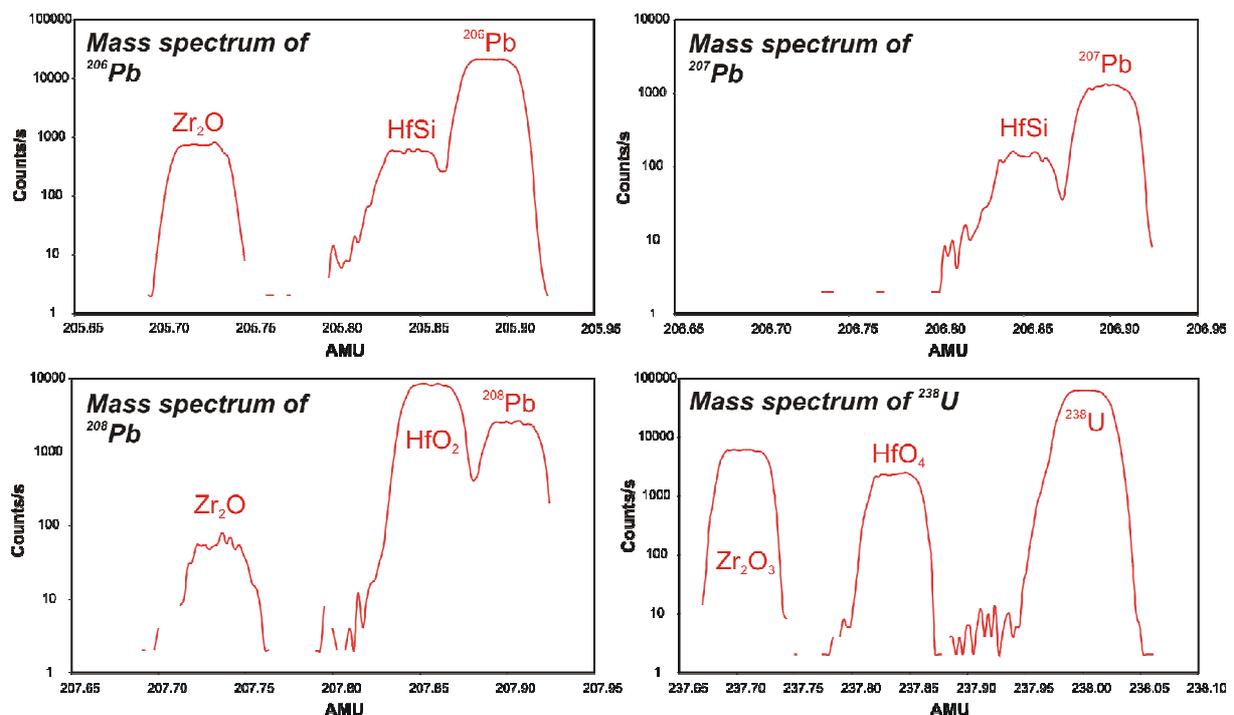
Fig.2: Mass spectrum of selected scanned masses showing separation of interferences in zircon (AMU=atomic mass unit).

The late-Caledonian Lochnagar granite

The Lochnagar Granite is located in the Grampian Highlands of Scotland (Fig.3) and comprises three main phases of intrusion (L1, L2, L3). Surrounding the Lochnagar Granite are several associated diorite intrusions (d1, d2, d3). The Lochnagar Granite has previously been dated using U-Pb whole-grain dissolution techniques (TIMS) of monazite (417±1 Ma) and zircon (426±2.5 Ma) [2]. However, whole-grain analysis does not allow investigation of individual zones and important information may be lost. Thus, next to determining the age of the Lochnagar Granite and the order of emplacement of the pluton's intrusive phases the aim of this *in situ* study was to examine individual zones (and possibly older inherited material)

Fig.3: Map of Scotland showing the location of the Lochnagar Granite.

within the zircons, which may reveal important information about the origins of the granite source rocks and the lower crust beneath Lochnagar.

Results & Conclusions

According to field observations the order of emplacement is L1, which was intruded by L2 and then by L3. No field relationships between L3 and L2 have been observed. The diorites are inferred to be slightly younger than the main Lochnagar granite body. However, the results from this study show that there are no clear age differences between the granite phases or diorites (Fig.4). Although the diorites appear to be slightly younger, all ages are within analytical error. A further result is that no inherited material was found in any of the analysed zircons.

The data show that Phanerozoic zircon grains can be dated successfully and with high precision (c.1%) using the Cameca ims1270. The Lochnagar granites and diorites all crystallised at c. 421±4 Ma, but it is not yet possible to detect minor age differences between the three Lochnagar phases or the diorites. Further U-Pb work on additional L1, L2 and L3 granite samples may clarify, if age differences between the intrusions exist or if intrusion of the different phases of the Lochnagar pluton occurred within a time span too short to be resolved by this technique.
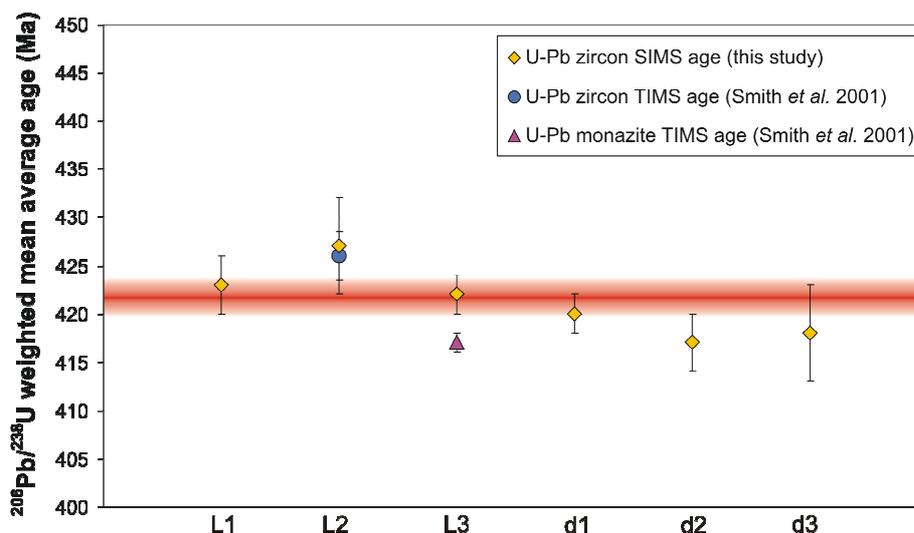
Fig.4: $^{206}Pb/^{238}U$ weighted mean average age (Ma) of Lochnagar granites (L1, L2 & L3) and diorites (d1, d2 & d3) obtained in this study. Red area shows that all samples more or less lie within analytical error of each other. For comparsion TIMS ages for L2 and L3 by Smith et al. (2001). Error bars are 2σ.

References
[1] G. Faure & T.M. Mensing (2004). Isotopes: principles and applications. 3rd ed., John Wiley & Sons, Inc., Hoboken, New Jersey.
[2] C.G. Smith, S. Goodman & S. Robertson (2001). Mem 1:50 000 geological sheet (65E), Scotland, BGS.