Geothermal potential of some Caledonian granitoids in Ireland

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Introduction

Granitoids generally have the highest abundances of radioactive heat-producing elements – uranium and thorium hosted in accessories such as zircon and apatite, and potassium in major minerals such as biotite and K-feldspar. Buried granitoids are potential sources of geothermal energy, but their heat production rates, the thermal insulation afforded by the overlying rocks and the particular structural setting require detailed investigation.

The Drogheda and Kentstown granitoids are of late Caledonian age[1,2] and occur within the Iapetus Suture Zone. They are overlain unconformably by up to several hundred metres of Carboniferous limestones, which are possible thermal insulators. The Crossdoney and Ballynamuddagh granitoids, which are analyzed for comparison, are presumably of similar age, but are located outside the Iapetus Suture Zone (Figure 1).

As part of the IRETHERM project we are investigating the geothermal potential of such granitoids using geochemical and petrophysical methods. We aim to understand the variation in heat production rates between granitoids in different geological settings and to determine whether this is related to granitoid petrogenesis, age, tectonic setting or is controlled by subsequent hydrothermal alteration. The initial geochemical and petrographic aspects of this work are presented here and further approaches are outlined.

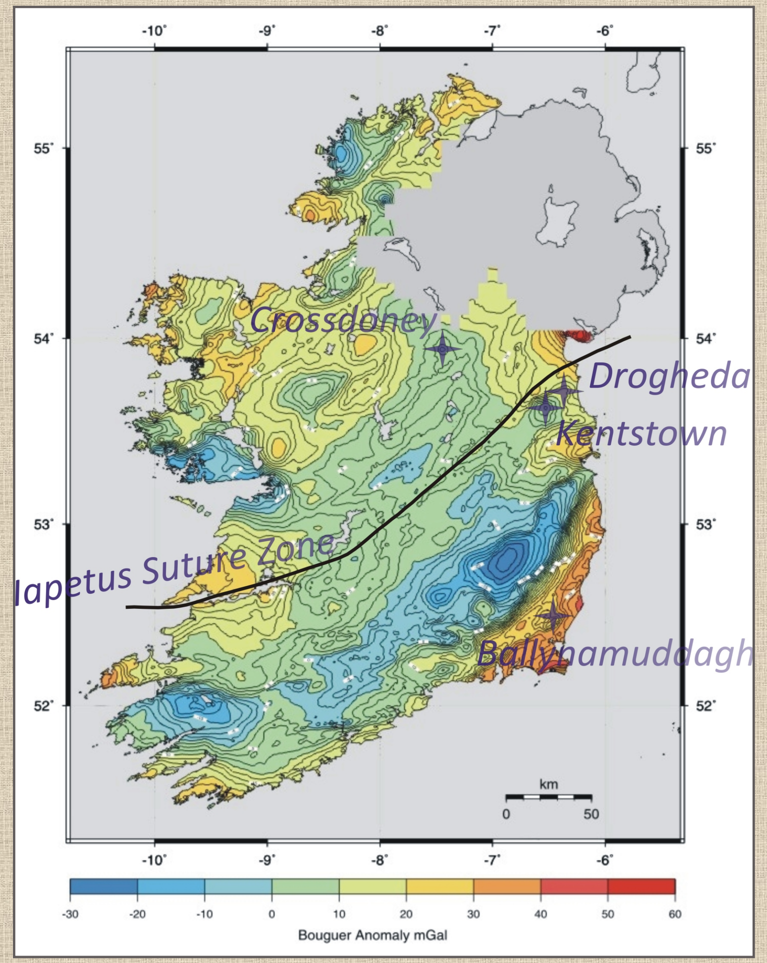


Figure 1:
Bouguer anomaly map of the Republic of Ireland[5]. Locations of the investigated granitoids are illustrated, as well as the progression of the Iapetus Suture Zone[6].

Implications for the geothermal potential

The Drogheda granitoid (a quartz-syenite to quartz-monzonite) has an average heat production rate (A) of around 4.8 μW/m^3, assuming a density (ρ) of 2.65 g/cm^3 (Figure 4). The Kentstown and Ballynamuddagh granites and the Crossdoney quartz-monzonite have a markedly lower estimated heat production of 1.5 - 2.4 μW/m^3, assuming the same density. This difference is mainly due to the variation in their thorium contents, since the Drogheda granitoid has a thorium content about ten times higher than the others, yet only slightly higher potassium and similar uranium concentrations (Figure 3d).

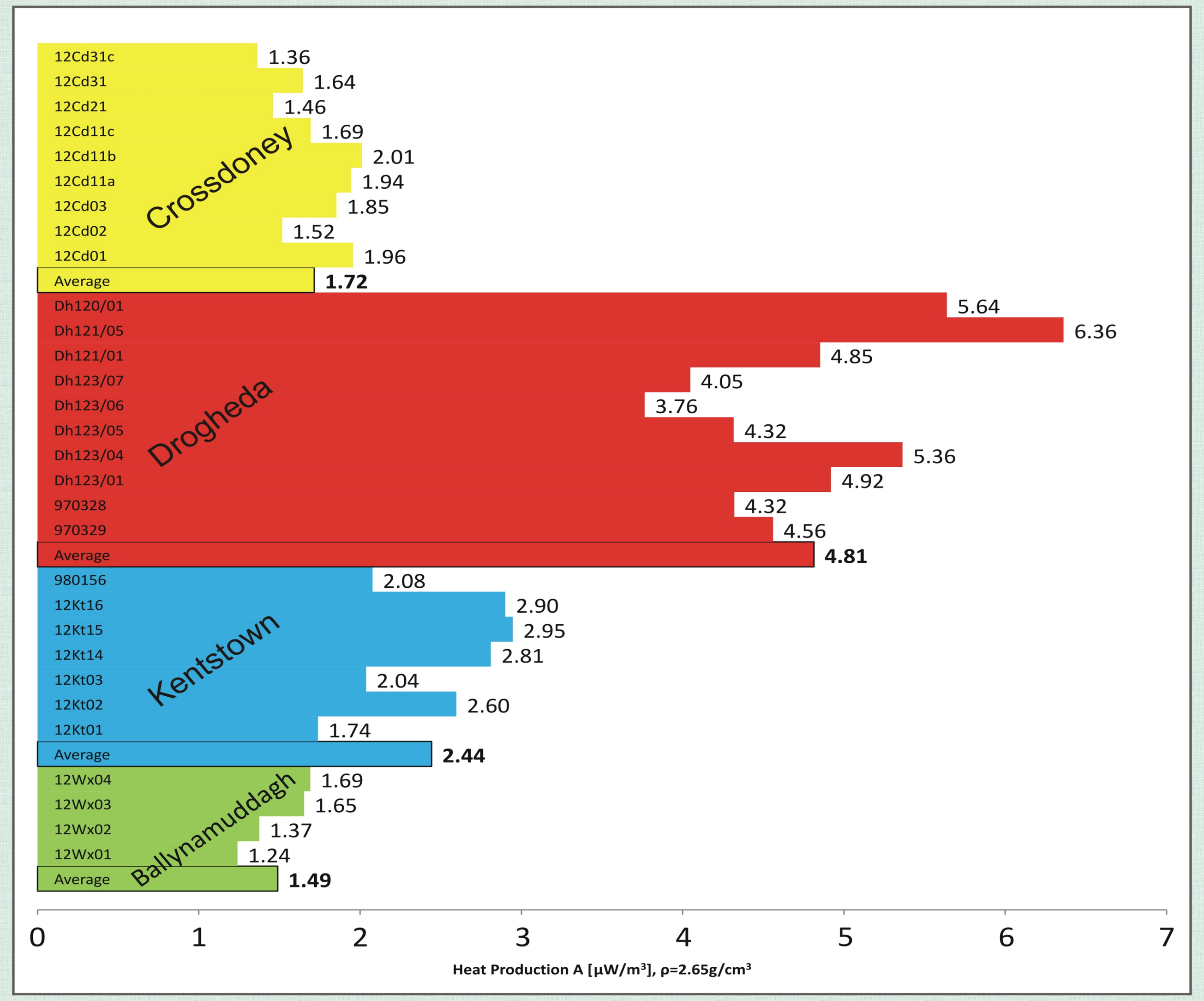


Figure 4:
Estimated heat production rate A (in μW/m^3) for each of the analyzed samples and averages for the distinct localities. All calculations using an assumed density ρ of 2.65 g/cm^3 for the granitoids.

The sedimentary cover rocks and their role as a thermal insulator

Mostly limestones, sandstones, and mudstones overly the investigated granitoids. They are generally considered likely to serve as a thermal insulator, but the amount of pore space and its infill also play a decisive role in terms of their thermal conductivity (Figure 6, 7). Hence, water or air-filled pore space and a purely micritic matrix would be preferred for a thermal insulator[9].

Interlayered in the sedimentary cover rocks, layers of shales occur. The possibility that they may be significant radioactive heat producers is also being evaluated. However, if the shales only occur as thin layers, as suggested for all localities[3, 4, 10], this can likely be ruled out.

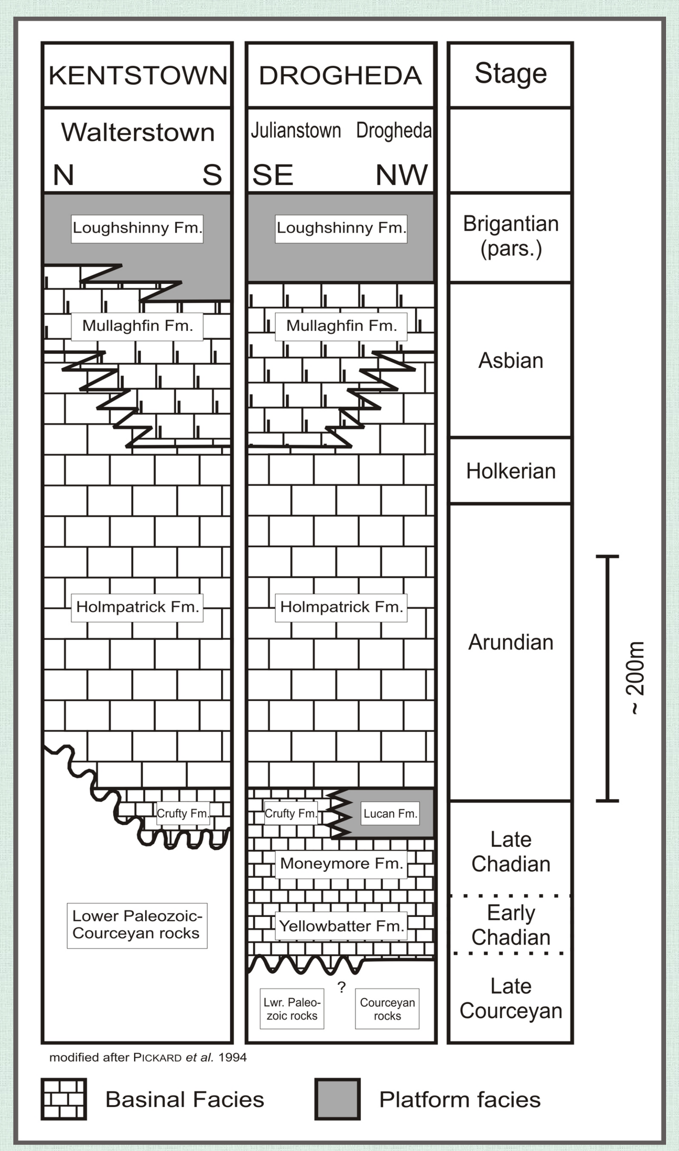


Figure 6:
Stratigraphic profiles illustrating the Carboniferous cover sequence which unconformably overlies the Drogheda and Kentstown granitoids. As this cover appears to be only a few hundred metres thick, the potential geothermal target may have suffered significant conductive heat loss.

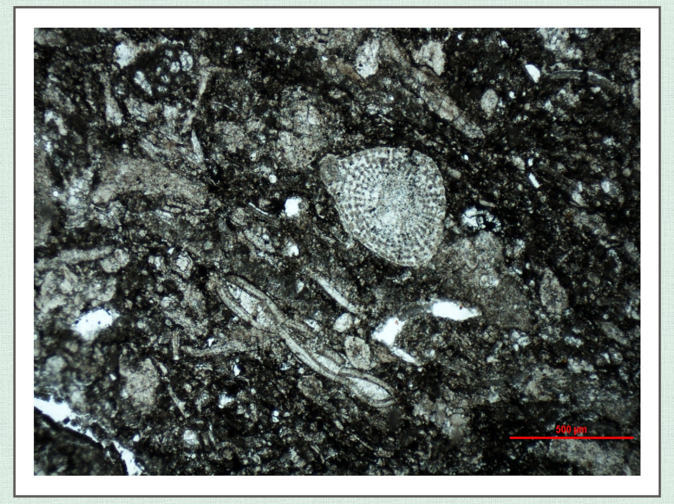
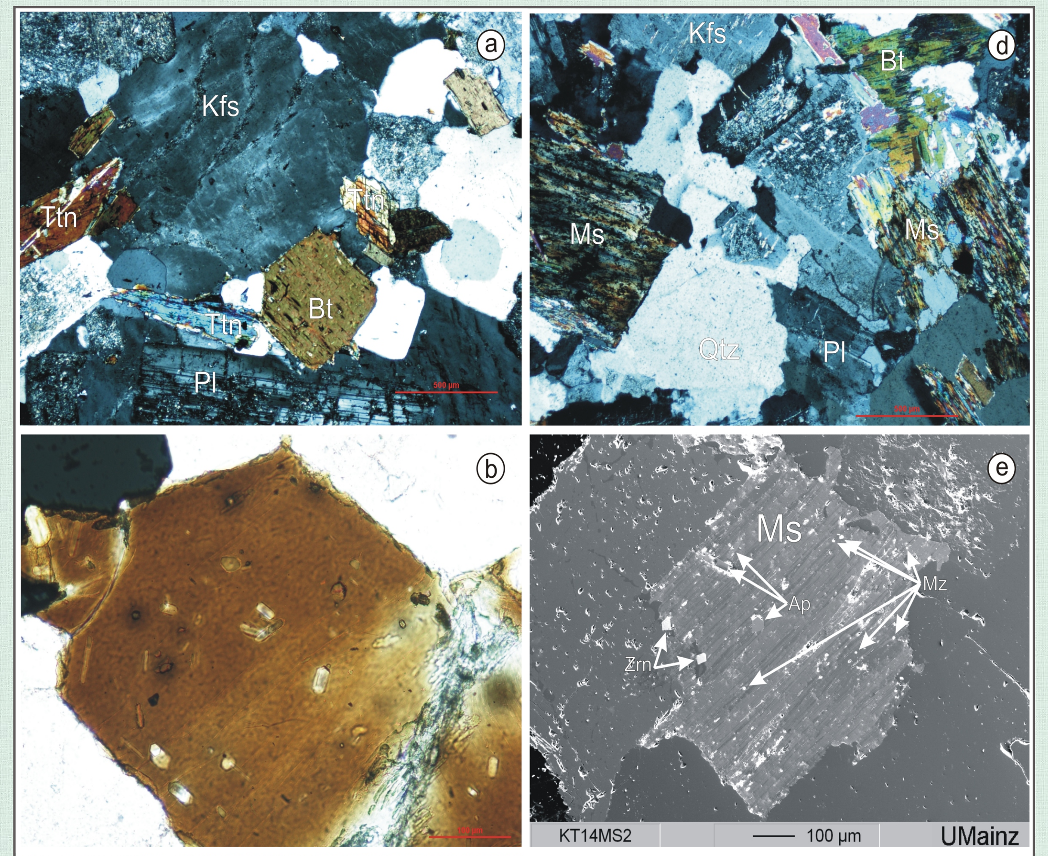


Figure 7:
Packstone to grainstone from the Lucan Formation (Figure 6), exhibiting orientated shell fragments, an Ostracod and a coral imbedded in a fine matrix of micrite (grey) and clay minerals (black). Although limestones generally have a low thermal conductivity, it could have been increased in this case due to diagenetic compaction and cementation of the pore spaces.

Geochemical characterization



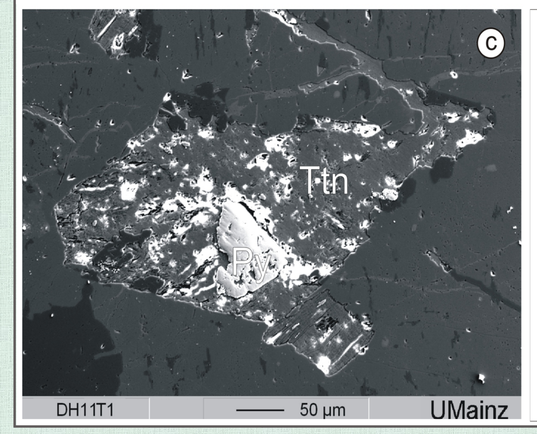
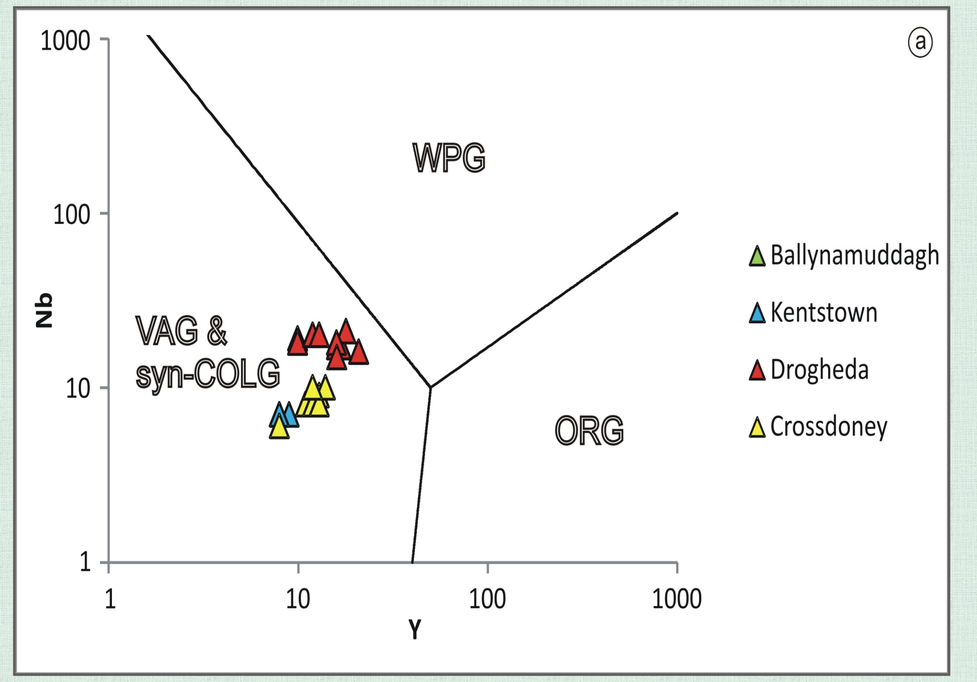


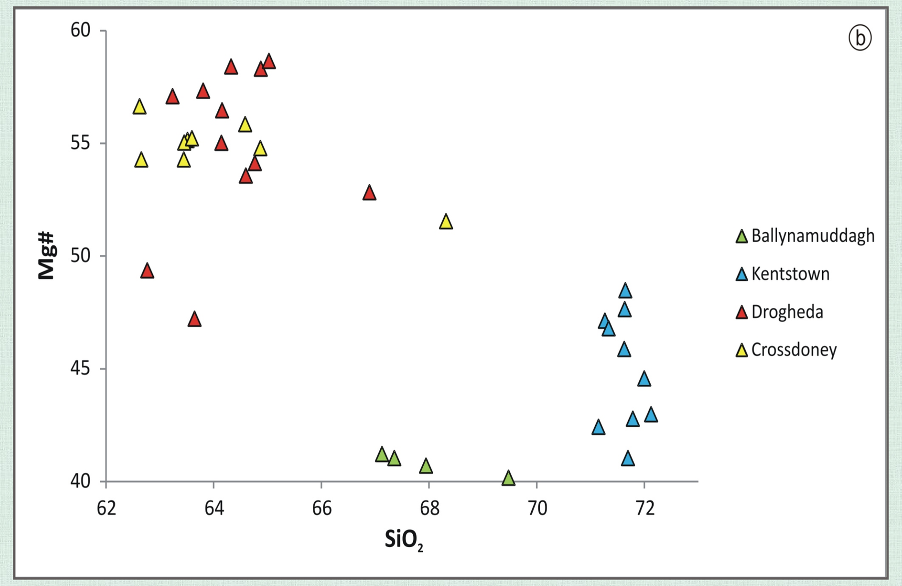
Figure 2:
Petrographic variations in Drogheda (Fig. 2a-c) and Kentstown (Fig. 2e,d) granitoids: a) Drogheda granitoid displays K-feldspar, sericitized plagioclase, biotite and abundant titanite; b) biotite crystal with zircon (pleochroic halos) and apatite (prismatic/acicular) inclusions; c) BSE image of titanite enclosing pyrite; d) Kentstown granite exhibits sericitized plagioclase, perthitic K-feldspar, chloritized muscovite and biotite; e) BSE image of muscovite enclosing plenty of monazite as well as apatite and zircon inclusions.

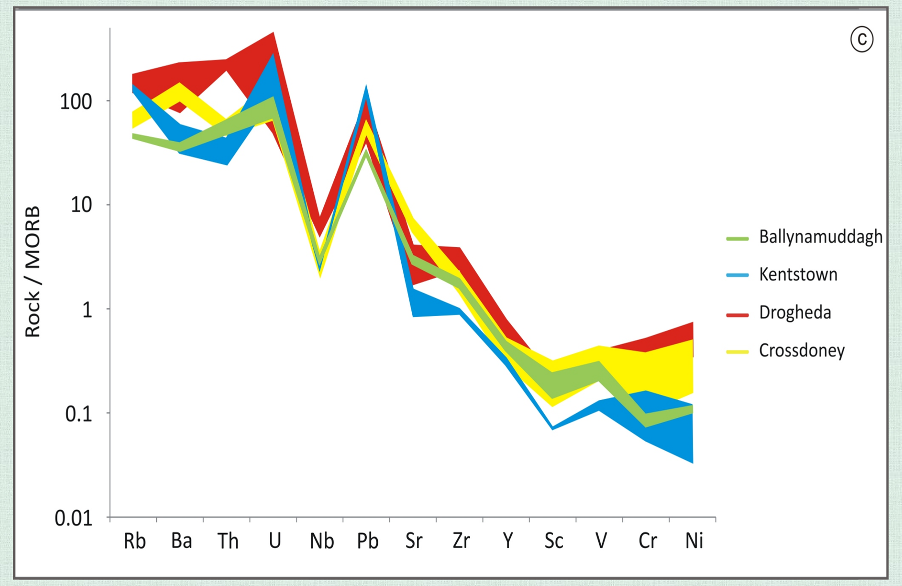
In spite of their related origin (Figure 3a), the four granitoids are distinct mineralogically (Figure 2) and geochemically. The Drogheda granitoid is petrologically relatively 'primitive' (Figure 3b), yet exhibits generally elevated trace elements (Figure 3c). Further major discrepancies, compared to the other granitoids, are its high sulphur content (up to 1.7 wt%) as well as abundant titanite mineralization.

Contrasting this, the Kentstown granitoid is more leucocratic and displays a lower trace element pattern. Although it has a comparatively low Th concentration (Figure 3d), it is abundant in monazite and thorite has been detected.

Mineralogical and geochemical similarity generally appear between the Drogheda and Crossdoney granitoids as well as between the Kentstown and Ballynamuddagh granites.







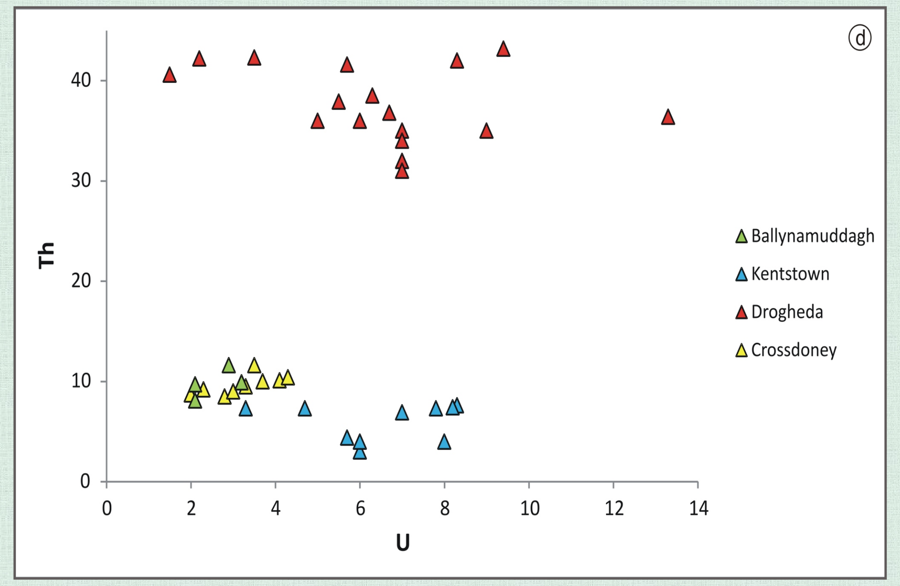


Figure 3:
Variations in major and trace elements for the distinct granitoids: a) Nb versus Y (in ppm) discrimination diagram, illustrating the genesis of the granitoids in an orogenic setting. The fields shown[8], are for volcanic arc granites (VAG), syn-collisional granites (syn-COLG), within-plate granites (WPG) and ocean-ridge granites (ORG); b) Mg# versus SiO_2 (in wt%), exhibiting the close relationship between Drogheda and Crossdoney granitoids in terms of their major element compo-sitions; c) ranges of trace elements normalized to n-MORB composition[5], displaying the differences between the geographically closely related Drogheda and Kentstown granitoids; d) Th versus U (in ppm), showing similar ranges for U, yet elevated Th concentrations in Drogheda granitoids.

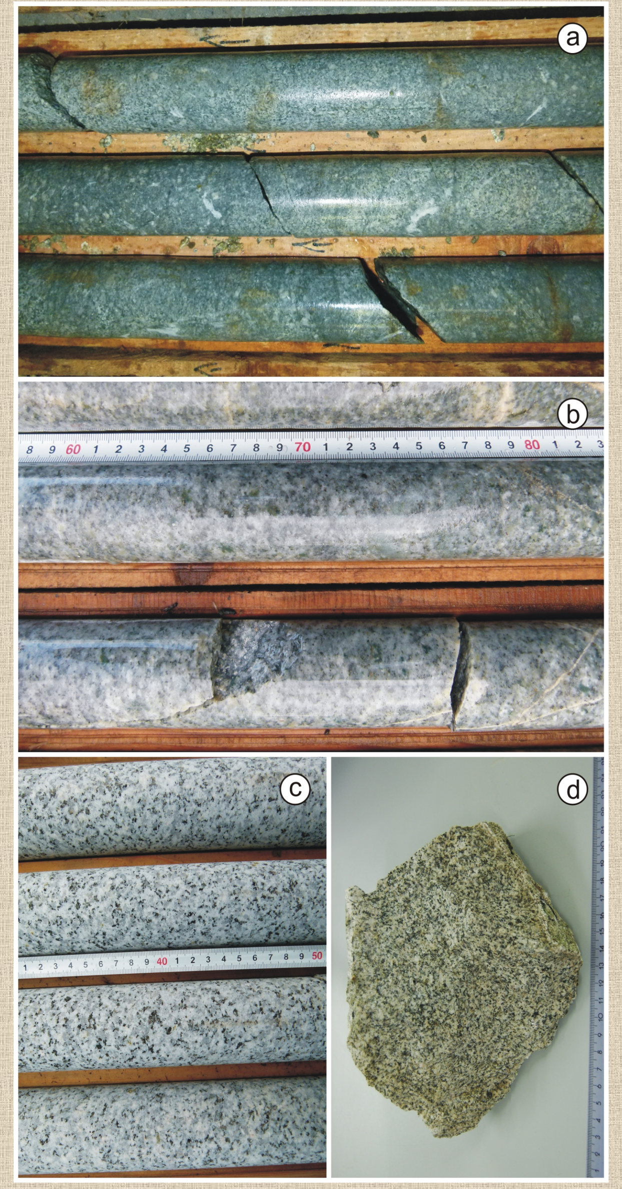


Figure 5:
Drillcores of a) Drogheda, b) Kentstown, and c) Ballynamuddagh granitoids, and d) hand specimen of Crossdoney granitoid

Discussion and outlook

Preliminary data show that the heat potential of the various granitoids differs significantly. The Kentstown granite exhibits low thorium concentration along with low contents of other minor and trace elements characteristic for monazite (P, Ce, La, Nd), although the latter mineral is present in the rock. Hence, the role of monazite fractionation as a possible mechanism controlling the granitoid's heat production will be evaluated. In addition, particular source materials, from which the granitoids derived, can certainly play an important part in determining the heat production potential.

It is hoped that further geochemical investigations (isotope, major and trace element analyses) will reveal the extent to which also alteration, fluid-rock interactions and AFC processes have affected the differences in the granitoids' heat production rates. The petrogenesis and age of these and similar granitoids will form the focus of future research. The overall aim is to contribute to a better understanding of 3D variations in heat production rates and improve exploration strategies for geothermal energy.

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