Method Overview
The U-Th-Pb radioisotope system is the basis for one of the most important geochronometers in use today. It exploits three independent radiogenic isotopes 238U (t1/2=), 235U (t1/2=), and 232Th (t1/2=) that together can be used to date events from the beginning of the solar system to the Pleistocene. This versatility, along with the ubiquity of minerals containing high U and Th concentrations (i.e., zircon, titanite, monazite, baddeleyite, apatite, rutile, etc.), has led to the use of U-Th-Pb geochronology in the study of igneous, metamorphic, and sedimentary systems. U-Th-Pb geochronology is also used as the standard by which all other geochronologic methods are compared and in some cases has been used to calibrate decay constants for other radioisotope systems. Recent advances in analytical techniques have improved precision of U-Th-Pb age determinations, reduced the sample volume needed for analysis, and reduced analysis time such that U-Th-Pb geochronology has become the most widely used chronometer in the study of deep time.

Sampling and Mineral Separation
The closure temperatures (temperature below which diffusion of Pb is negligible) of high-U minerals span a large range from >900˚C for zircon to 400˚C for apatite. Therefore, the sampling strategy and mineral separation techniques used will depend on the individual project’s goals. Nevertheless, most projects will require sampling a rock in the field, crushing or disaggregating the rock to liberate individual minerals, and density and magnetic separation techniques to isolate the mineral of interest. A key component of all these steps is carefully avoiding sample contamination through careful treatment of the sample in the field to keeping a clean laboratory for crushing and mineral separation. Helpful information for how zircon (the most commonly used U-Pb chronometer) is separated can be found at earth.boisestate.edu/isotope/labshare.

One advantage of U-Th-Pb geochronology is that the three radioisotope systems 238U — 206Pb, 235U — 207Pb, and 232Th — 208Pb can be used as a check that the system has remained closed since the crystallization of the mineral of interest. This can be done on several concordia diagrams by ensuring that both dates provide the same age, or are ‘concordant’. A fourth isotopic system can be used by combining the 206Pb/238U and 207Pb/206Pb age equations and assuming a constant terrestrial 238U/235U. This system utilizes only the 207Pb/206Pb ratio and is useful when the target mineral has experienced recent “Pb-loss” (preferential loss of Pb from the target mineral through zones of high radiation damage) as this process does not affect Pb isotope systematics.
Analytical Techniques
The most commonly used methods are isotope dilution-thermal ionization mass spectrometry (ID-TIMS), secondary ion mass spectrometry (SIMS), and laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). Each technique has advantages and disadvantages in analysis duration, cost, precision, and volume of sample material needed.

ID-TIMS is the most expensive and time consuming method (3-4 hours + lengthy sample preparation), and involves dissolution of part, or all, of the target mineral. However, the technique provides the most accurate and precise (typically <0.1% for zircon) dates possible and data produced by this technique are used to calibrate standard reference materials and the geologic timescale. When the highest precision analyses are needed, this is the go-to method.

SIMS and LA-ICP-MS analyses are much less destructive and are typically done by ablating the target mineral's surface with either a focused ion beam (SIMS) or a high energy laser (LA-ICP-MS) either on separated crystals or directly in polished petrographic thin sections. Both techniques routinely produce dates with moderate precision (~2-4% for zircon) and are relatively fast (30 minutes: SIMS; 1-2 minutes: LA-ICP-MS). These techniques are also relatively inexpensive. They are best suited to analysis of complex minerals with many small-scale growth domains or projects where age precision of 1-2% will not limit geologic interpretations.

In any case, the best results will be obtained through collaboration with U-Th-Pb geochronologists who can help figure out which method is most appropriate and assess the limitations of a given dataset and ensure analysis quality.

Petrochronology
An exciting aspect of modern U-Pb geo-thermochronology is the possibility of combining U-Pb dates with the trace element composition of the analyzed mineral. This can be done simultaneously during LA-ICP-MS analyses by splitting the volume of ablated material and feeding it into two mass spectrometers using the laser ablation split stream (LASS) method or by analyzing aliquots of the dissolved material produced during ID-TIMS analyses using the TIMS-TEA method. These analyses can measure REE or trace element patterns that can be linked to phase assemblages that were present during the mineral’s crystallization or can measure isotopic data that can shed light on the mineral’s origin (i.e., Hf isotopes in zircon). Ultimately, the goal is to provide the most petrologic context possible for each U-Pb age.

Useful Websites
www.earth-time.org
Organization focused on calibrating Earth history by increasing inter-laboratory reproducibility. This website is a great resource for learning about high-precision ID-TIMS geochronology.

www.plasmage.org
Organization focused on increasing precision and accuracy in LA-ICP-MS analyses. This website is a great resource for information regarding best practices for LA-ICP-MS analyses.

www.earthscope.org/research/geochronology
Program for graduate students interested in being connected with a geochronology laboratory and applying for funding to visit that lab and get data.