PROVENANCE STUDIES FOR THE OIL INDUSTRY

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What are provenance studies and what can they do for me? This is probably the question you are thinking after reading the title. Provenance studies are carried out by sedimentologists to try to identify the source of sediments now residing in the basin. The purpose of such a study is to try to explain or predict if other features of the basin, such as sedimentary architecture, also could have changed when it is difficult to know otherwise. Ultimately data from provenance studies feeds into reservoir model building and understanding the stratigraphy of an interval of interest.

Provenance studies involve several techniques which are used to analyse the coarse silt to fine sand fraction (40-250 µm) of a sedimentary rock from core or cuttings samples.

HEAVY MINERAL ABUNDANCES

The first technique is used to determine composition of the heavy mineral assemblage of the sample of interest. Heavy minerals are accessory minerals, such as garnet, apatite, zircon, chrome-spinel etc., which make up a small proportion of the rock (commonly less than 1%). Commonly sandstones contain high abundances of quartz, feldspars and micas. Quartz in particular is resistant to abrasion and chemical attack and so becomes concentrated in sediments and can also be recycled through several generations of deposition and exhumation meaning they are not diagnostic of a particular provenance. Unlike quartz, heavy minerals can be diagnostic of certain igneous and metamorphic rocks, and assemblages of heavy minerals can be linked to source terranes. Analysis of heavy minerals involves the separation of these minerals from lighter minerals in the sandstone using heavy liquids. Following this the heavy minerals are mounted on a petrographic slide for microscopic analysis. The abundance of heavy minerals in a sample is then determined by identifying and counting at least 200 non-opaque and non-micaceous minerals present in a sample to produce a statistical data set e.g. table 1. The abundance of heavy minerals typically changes with time, reflecting the evolution of the source mountain belt, which can be detected in a study section (Figure 1).

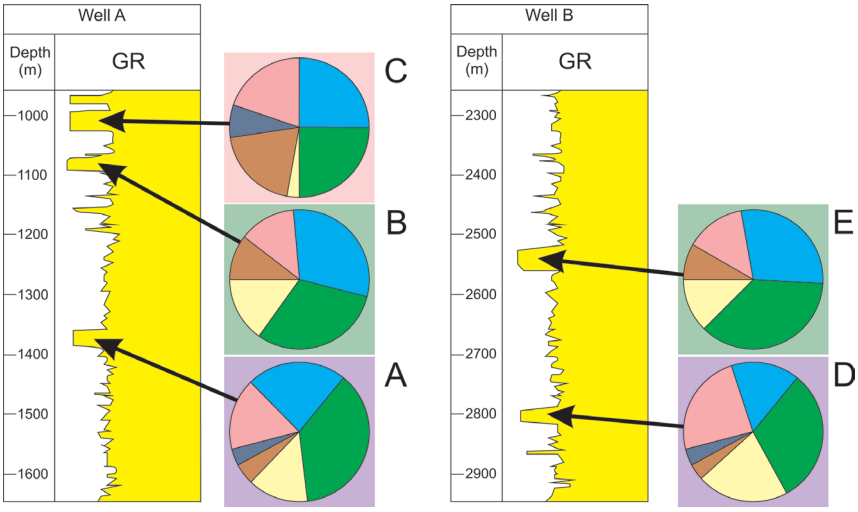
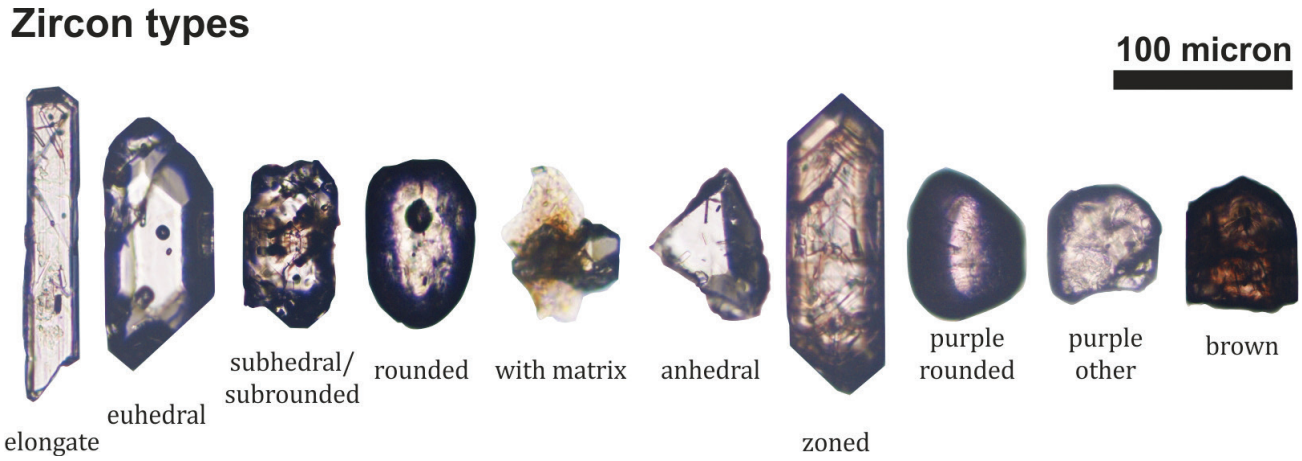


Figure 1: Variation of heavy mineral abundances with depth allows changes in provenance to be determined and correlations made. Mineral proportions are shown as pie charts. Refer to table 1 for mineral colour codes. Compositions of B and E are similar, as are A and D, implying they belong to the same provenance systems (green and purple backgrounds). The composition of C is dissimilar to all other samples, having a larger proportion of tourmaline identifying it as having a third provenance.

Mineral	Garnet	Zircon	Apatite	Tourmaline	Rutile	Anatase
Count	31	45	7	156	37	15
%	11	15	2	54	13	5

Table 1: An example of heavy mineral composition of a sample.



HEAVY MINERAL MORPHOLOGIES

The proportion of heavy minerals in a sample is not the only useful information that can be gleaned from microscopic analysis of the coarse silt and fine sand fraction. Grain morphology also contains information about transport history and can be used to subdivide the population of one mineral into sub-populations which can be related to transport duration and so estimate if the source was more proximal or distal (Figure 2). This might be particularly useful in choosing between two possible provenances which were identified because they had the right heavy mineral composition but were situated different distances from the location in the basin. Typically morphological analysis groups grains into categories ranging from rounded to euhedral, with euhedral likely to originate at a more proximal source.

Figure 2: Morphology of zircon grains seen under the microscope. Note the euhedral grains, indicating younger grains or limited time in a sediment transport system, and well-rounded grains indicating prolonged time in a transport system.

DATING SEDIMENTS

The third technique commonly carried out is U-Pb dating of zircon or apatite crystals found within the heavy mineral fraction. This is an isotopic technique which determines the proportion of parent and daughter isotopes in a zircon or apatite crystal from the uranium to lead radioactive decay pathways and uses these to calculate the age

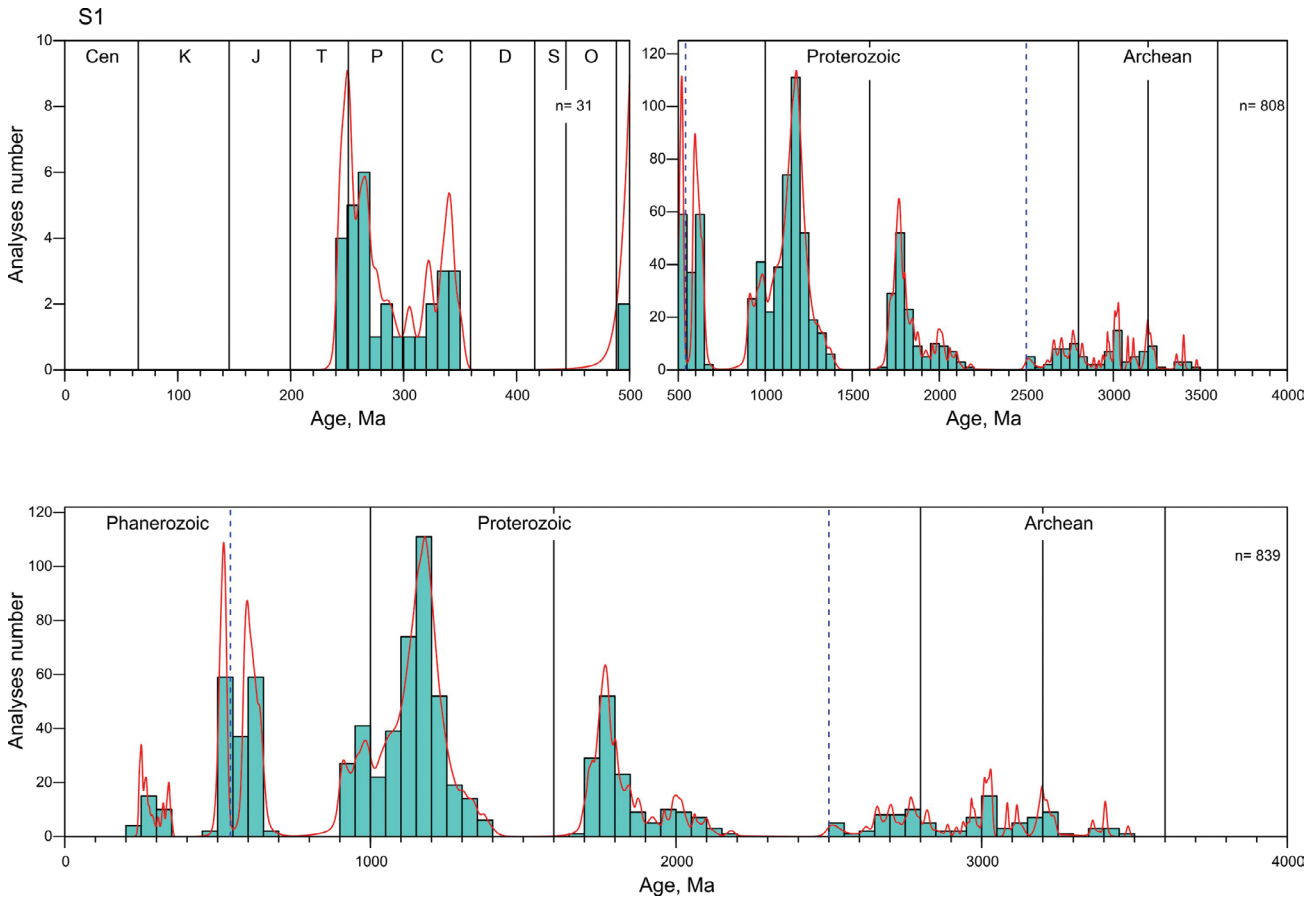


Figure 3: Age distribution plots for detrital zircons shown using two conventional plot styles: expanded Phanerozoic (above) and with a continuous scale (below). Broad peaks can be related to the age of orogenic events or magmatic episodes in cratons or other source regions adjacent to the basin of interest.

of formation of the crystal based on known decay rates. Usually a population of grains are analysed and a range of dates are obtained. Each age is the time that has passed since that crystal formed in a magma chamber, at which point the uranium and lead daughter isotopes were trapped in the crystal as it solidified. Since that time uranium has decayed into lead with the release of energy (nuclear fission) trapping daughter products in the mineral. The population of grain ages are commonly displayed in a frequency histogram (Figure 3 blue bars) or as a probability density function plot (Figure 3 red line). These plots commonly show broad peaks of higher frequency which are interpreted to represent orogenic (mountain building) events. During orogenic events rocks which normally reside deeper in the earth's crust are exhumed, including solidified magma chambers, and this produces an influx of zircons and apatites into the basin. Orogenic events are also times of increased volcanic activity which leads to an input of zircons and apatite into the sedimentary record from volcanic ashfall and extrusive events.

A POWERFUL MEDLEY

Combined together these three techniques provide a powerful medley of tools for understanding sediment provenance and pathways. Common scenarios could be, for example, that several provenance sources could contain similar heavy mineral assemblages to the study sediments, but only one would have been formed at the same time as the age distribution of zircons from the basin, and would be the right distance from the basin as indicated by grain morphology. Thus of several possible source areas only a single source ticks all boxes. Provenance data also acts to rule out proposed sources, for example cratons closest to the basin, as in some cases this geographic type of reasoning doesn't work.

Provenance analyses such as these are even more powerful when several analyses are carried out throughout a stratigraphic section. In this way the changes in provenance can be determined and used to explain changes in other parameters such as sedimentary architecture and palaeogeographic analysis relating to longer term, larger scale tectonic processes.

Where laboratory expertise and analytical equipment exists more advanced techniques can also be applied to further develop provenance studies, for example advanced petrographic techniques and grain chemistry analysis. Integration with other data sets, such as chemostratigraphy and biostratigraphy, can help produce a rich palaeogeographic story.