CLAY MINERALS AND SEDIMENTARY BASIN HISTORY

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Clay minerals are the main inorganic constituents of the soil and mud that coat the Earth's surface. This thin coating of clay is formed by chemical reactions between water and rock during weathering and has been an important part of Earth's life-support system since microbes and fungi colonised land surfaces around a billion years ago. Without clay minerals rock dust would cover the Earth's surface, as it does on the Moon and other planets in the solar system. Almost all the clay minerals formed in surface soils and muds are recycled in the Earth's crust, a process that creates new crustal rock and also stimulates the production of magma from the underlying mantle (Merriman, 2002).

Sedimentary basins are an important stage in the clay cycle. Here clay minerals go through a series of diagenetic and metamorphic reactions that transform soft muds and clays into lithified mudrocks. Up to 65% of the rock types found in sedimentary basin are mudrock lithologies, including mudstone, shale and slate, with clay minerals the dominant component. As sedimentary basins deepen and fill, the nature and origin of the clay minerals change (Eberl, 1984). Detrital or *inherited* clay minerals are initially transported into sedimentary basins with little modification after erosion from hinterland outcrop. Other clay minerals are newly formed, or *neoformed*, during early sediment accumulation, either by direct precipitation from solution or by replacement of glassy volcanic ash. With increasing sediment thickness, i.e. depth of burial, both inherited and neoformed clay minerals are *transformed* to mature diagenetic and low-grade metamorphic clay assemblages. The relative proportions of inherited, neoformed and transformed clays can be related to the geotectonic setting and to the thermal history of different types of sedimentary basin (Fig 1).

The rate at which clays react to form equilibrium assemblages varies from 1×10^4 years in some hydrothermal systems, to around 2×10^9 years in some mid-continental rift basins (Merriman, 2005). A wide variety of factors contribute interactively to clay mineral reaction rates in sedimentary basins, including heat flow, fluid movement and composition, overburden pressure/overpressure, and tectonic deformation. When clay mineral reaction progress is correlated with organic maturity three types of sedimentary basin can be recognised. *Immature basins* have not reached the oil window and are dominated by neoformed and inherited clays of the shallow diagenetic zone. Basins of this type may have experienced rapid reaction rates during the neoformation of clays, as for example in saline lakes, but have not been buried deeply enough to develop transformed clay mineral assemblages. However, some rapidly subsided, deep basins can remain immature because of low heat flow and the reaction-inhibiting effects of overpressure. Clay mineral assemblages in immature basins can provide information on sediment provenance, and are also the main source of commercial clay deposits such as bentonite. *Mature basins* are generally within the oil and gas windows, and characterised by the transformation of neoformed and inherited clays in response to deep burial diagenesis. The smectite-to-illite transformation is usually completed at this stage of basin maturity, and well-lithified mudstones and shales are characteristic mudrock lithologies. In high-heat flow basins, such as back-arc or marginal basins, clay mineral maturity is achieved relatively rapidly even under a thin overburden. In low heat-flow basins, such as fore-arc basins and some passive margin basins, clays are slow to mature even under a thick overburden.

Supermature basins lack any hydrocarbon potential, and represent the early stages of metamorphism. Deformation plays a crucial part in completing the transformation of metastable diagenetic and inherited clays to equilibrium assemblages of white mica + chlorite ± pyrophyllite. However, the geotectonic setting and paleogeothermal characteristics of the pre-metamorphosed basin can be preserved in the diversity and chemistry of the transformed clays (Fig. 2). In British Caledonian terranes many of the extensional back-arc basins, characterised by high heat flow (>35ºC/km) and associated hydrothermal activity, tend to have a greater range of transformed clay minerals, including K-, K/Na- and Na-micas and pyrophyllite, as well as chlorite/mica stacks. K-white micas in these assemblages are typically aluminous with *b* cell dimensions <9.01Å (Stone & Merriman, 2004; Merriman, 2006). In contrast, low heat-flow basins that are characteristic of convergent margins, tend to have less diverse transformed clay mineral assemblages of simply K-white mica and chlorite, and the K-micas are phengitic with *b* cell dimensions >9.02Å. Thus the nature and composition of transformed clay mineral assemblages in supermature basins can be used to unravel the history of fold belts.

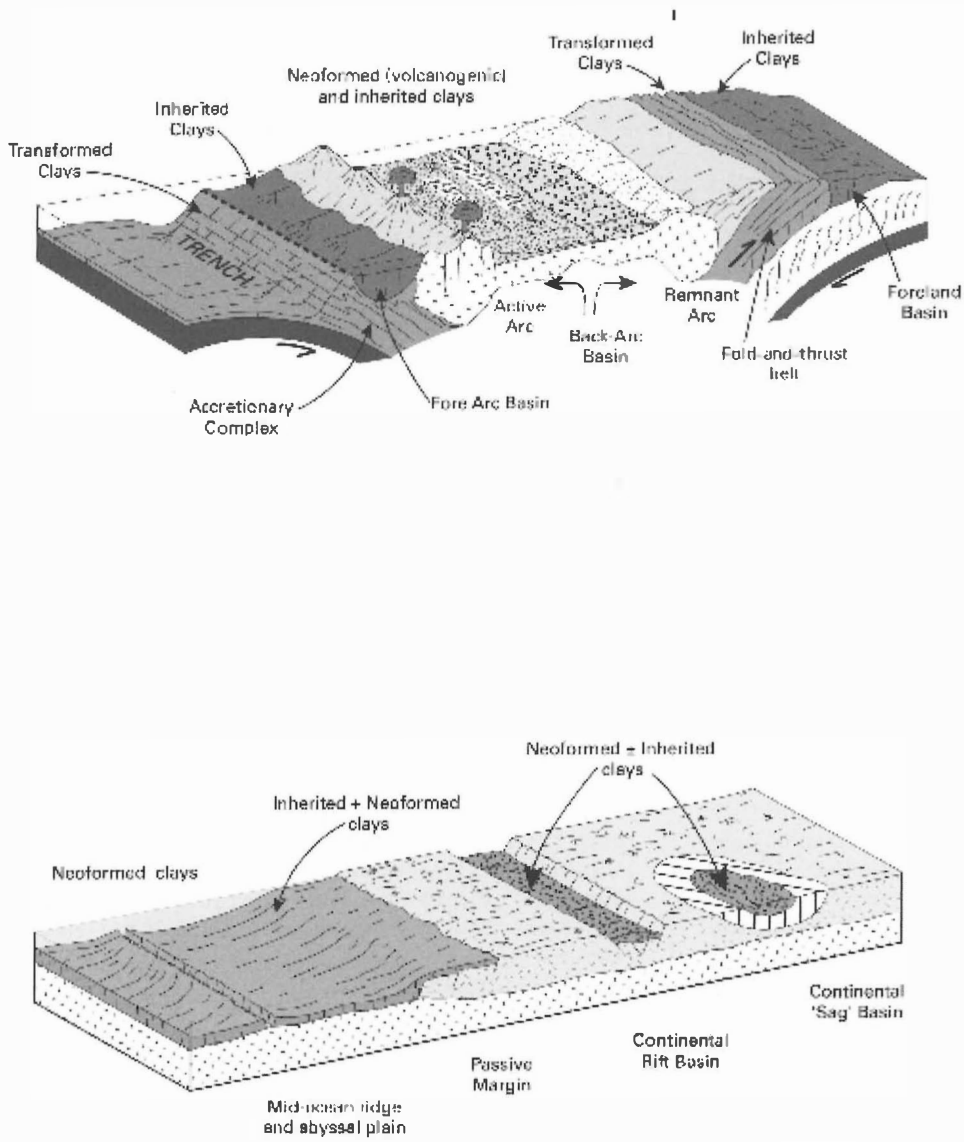

Figure 1: The origin of clay minerals in different geotectonic settings (Merriman, 2005). (a) Basins formed in active margin setting. Extensional back-arc basins contain inherited clays from volcanic arc and hinterland terranes, and also neoformed volcanogenic and hydrothermal clays formed in situ. *Fore-arc and foreland basins mainly contain inherited clays from eroded mountain belts. Inherited clays in accretionary prisms are transformed to low-grade metamorphic clays during underplating; transformed clays also predominate in fold-and-thrust belts. (b) Basins formed at passive margins or within plate settings may retain a higher proportion of neoformed clays. Inherited clays are predominant in typical passive margin basins, but shallow shelf basins on passive margins may contain a high proportion of neoformed Fe-rich clays. Neoformed clays also form around mid-oceanic ridge systems and in basalt-floored oceanic basins. Continental rift basins have significant amounts of neoformed clays. Inherited clays predominate in continental 'sag' basins formed on shields with varied topographic relief.*

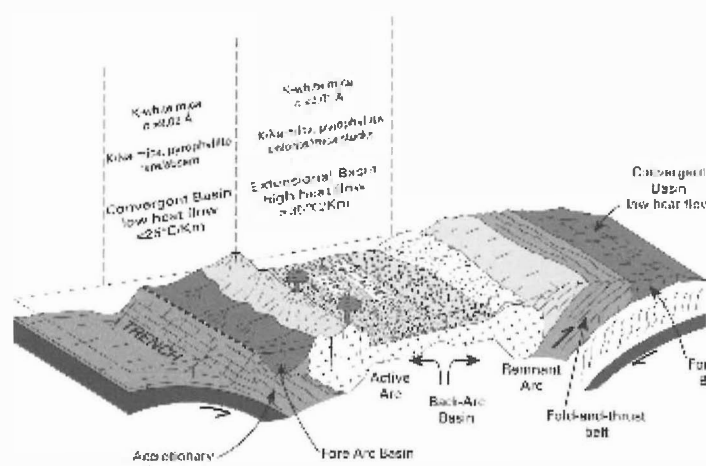

Figure 2: Schematic diagram illustrating differences in clay mineralogy typical of convergent and extensional basin settings in British Caledonian terranes (Merriman, 2006).

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