

Utility and frontiers of metamorphism
Notes by D Pattison 2006-Dec-04

The following message was sent out to the *Geometamorphism* list-server:

Hi all. November 6, 2006

What do you think are the most interesting and dynamic research areas in metamorphic petrology? What are the frontiers in our field? Where do you see metamorphic petrology interfacing with other sciences and with issues of broader societal interest?

When members of the public and other science disciplines find out you do metamorphic petrology and ask why you do it and (more bluntly) what good is it, what do you say?

The resultant discussion thread generated 18 responses (names listed below), which I have summarized below along with my own thoughts. The responses can be roughly divided into two categories: 'What use is metamorphic petrology?' and 'Frontiers in metamorphic petrology'. There is quite a lot of overlap between the two. The first category generated the most responses.

1. What use is metamorphic petrology?

There was one overarching response/theme:

Metamorphic petrology is an integral component of the interdisciplinary study of lithosphere evolution through time

We are one of an interconnected web of disciplines contributing to the understanding of the evolution of the solid Earth, especially the lithosphere. We bring unique and essential expertise to bear, as do geophysicists, structural geologists, geochemists, geochronologists, sedimentologists. In order to provide the best possible contribution, we need to continue to improve our most important tools (e.g., understanding mineral assemblages, mineral compositions and textures, P-T-t estimation, fluid behaviour, microstructures), and communicate to other scientists and the public at large how these tools work and are useful to address questions of mutual interest.

Analogy: to build a house that is strong, warm, has light and running water, you need many different tradespeople, each of whom is expert in their trade, and each of whom depends on and trusts the expertise of their fellow tradespeople. Everyone's contribution is essential for the whole to function; deficiency of one trade leads to deficiency of the whole. 'Best practices' continually evolve in each trade, often driven by demand from others but requiring the focused attention of people in that trade. The best tradespeople are those who are good at what they do and can work with and communicate well with others.

More specific topics include:

Record of dissipation of Earth's heat

Earth evolution is largely the result of dissipation of Earth's heat through time. This involves many phenomena, but the general study of pressure-temperature-time variation in the rock record (ie, metamorphic petrology) is obviously key.

Metamorphic rocks are anomalies

Most metamorphic rocks are the result of thermal perturbations of Earth's lithosphere, whether higher-T than normal (Barrovian, Buchan metamorphism) or lower-T than normal (blueschist). Understanding the nature and causes of these perturbations is fundamentally interesting and is important to understanding how the Earth works.

Pressure-temperature-deformation-time (P-T-D-t) record of tectonic processes

Tracking the pressure-temperature-deformation-time (P-T-D-t) history of individual rocks in tectonic belts (mountain belts, subduction complexes), and comparing such histories among rocks from different parts of the same belt (eg, across metamorphic zones, faults) and among different belts, helps us understand the tectonic processes that have shaped Earth's lithosphere.

Metamorphic phase changes and plate tectonics

Density increases due to phase transitions (ie, metamorphic reactions) drive plate movements.

Metamorphic reactions and seismicity

Episodic progress of phase transitions (metamorphic reactions) can account for various types of seismic events in subduction zones. There is an interplay between fluid release, reaction progress and seismic activity.

Metamorphism and mountains, old and new

Mountains are some of the most significant continental landscape features, are the source of universal fascination and recreation, and have influenced the course of human history. Understanding metamorphic processes and P-T-D-t paths in the core of mountain belts helps us understand their formation better, and helps us identify where old mountain belts were, imagine what they were like (how high and how wide and how old), and predict where new ones may form.

Metamorphism and global cycling of volatiles: hydration and dehydration of the ocean crust

Seafloor (metamorphic) hydration reactions capture volatiles from the ocean that are later released in metamorphic dehydration reactions in subduction zones, fundamentally influencing the composition of the ocean and atmosphere.

Collisional orogenesis and the atmosphere

Metamorphic devolatilization of carbonate and silicate sediments occurs in collisional orogenic events, especially continent-continent collisions, with potential implications for broad climate patterns and cycles.

Metamorphic devolatilization and arc magmatism

Plate-margin magmatism, both in the mantle and crust, is caused in part by fluids released during metamorphic devolatilization reactions in subduction zones.

Continental magmatism

Understanding continental magma generation requires understanding the metamorphic melting reactions that produce these magmas – the granulite-granite link.

Rheology of the lithosphere

The thermal and mechanical behaviour of continents is dictated in part by metamorphic reactions and their rates, especially those involving partial melting and magma generation.

Understanding deep geophysics

Seismic velocity contrasts in the crust and mantle, and other geophysical patterns, reflect in part phase changes (metamorphic reactions). Metamorphic petrology also allows one to test competing theories for geophysical patterns, like electrical conductance anomalies in the deep crust (fluid presence vs. effect of graphite).

Inputs to geodynamic modelling

Metamorphic constraints are essential input data for coupled thermo-mechanical models of orogenesis.

Ore genesis and metamorphosed ore bodies

Metamorphic petrology informs the study of ore deposit genesis directly (e.g., link between metamorphic fluids and certain hydrothermal deposits) and indirectly (understanding the thermotectonic anomalies favouring ore genesis). Metamorphosed ore bodies and their altered host rocks show textural and mineralogical modifications, and may have experienced remobilization, all of which carry economic as well as scientific implications. In a metamorphosed ore body, seeing through the metamorphic overprint is necessary to understand the primary ore-bearing rocks.

Industrial and gem minerals

Metamorphism is responsible for the genesis of many industrial and gem minerals (garnet, wollastonite, asbestos, andalusite, ruby/sapphire, emerald, graphite, diamond). Metamorphic techniques are used to find them (eg, P-T estimation of kimberlite inclusions to see if they are in diamond window).

Metamorphism and CO₂ sequestration (mitigating climate change)

Metamorphic petrology principles, and rocks themselves, may play a role in CO₂ sequestration (carbonation-decarbonation reactions, meta-ultramafic rocks as potential sites of CO₂ sequestration).

Metamorphism and material systems

There has been feedback between metamorphic phase equilibria, experimental petrology and synthesis of materials (e.g., ceramics). Knowledge of metamorphic principles and metamorphic minerals may be used to design new industrial materials (e.g., zeolites and chemical filters).

Metamorphism and the origin of life

Some of the earliest remains of life are found in metamorphosed rocks (e.g., graphite); we need to understand the metamorphic overprint to see through it.

Application of metamorphic techniques and insight to other areas of geoscience

Metamorphic techniques and insights can and have been applied to other areas of geochemistry (groundwater contamination, weathering, diagenesis). Paleontologists have begun to do elemental mapping of fossils on the electron microprobe.

Metamorphism and archeology

Metamorphic petrology is used to trace the provenance of archeological artifacts.

Metamorphism and building stone

Metamorphic rocks are finding increasing application as building stone for a variety of purposes.

Intrinsic interest and utility of metamorphic rocks

Metamorphic rocks are beautiful and/or intriguing natural objects (some anyway), so people are intrinsically curious about them (witness rock shows).

2. Future areas of research

Continued refinement of phase equilibria and methods of P-T estimation

Phase equilibrium modelling – pros and cons of different approaches (linear equation approach, G minimization approach). There is a need to calculate phase diagrams rapidly and automatically to allow experimentation in modelling natural rocks (different chemical systems; different bulk compositions)

Kinetics - why does a metamorphic rock look the way it does? how do metamorphic reactions actually proceed at the microscopic and atomic levels? are metamorphic reactions over-stepped? how fast do metamorphic reactions proceed?

Interplay between phase equilibria and kinetics (need to understand both better in order to make sense of the mineral assemblages and textures in metamorphic rocks)

Interplay between metamorphism, microstructures and deformation – P-T-D-t studies.

What are we dating ? - linking of metamorphic petrology and geochronology (accessory phase petrogenesis); spatially resolved dating

Constraining geodynamic models of lithosphere

Interplay between metamorphism, melting and deformation, bearing on continental rheology and geodynamics

Mechanisms of UHP metamorphism and exhumation

Interplay between seismic activity, fault movements, subduction, phase transitions, metamorphic devolatilization.

Grain boundary fluids and material transport

Imaging of minerals using variety of techniques

Interface with materials science - strategic minerals, microstructure, nanotechnology and nanoscale processes

Interface with space exploration?

3. Contributors (in order received)

K Benn, M Rigby, S Mickleth, R Moraes, G Gosso, A Moeller, D Whitney, D Hirsch, N Harris, F Beunk, P Nabelek, S Cuthbert, D Gibson, T Feninger, S Chakraborty, A Souren, J Rosenfeld, J Obenholzner