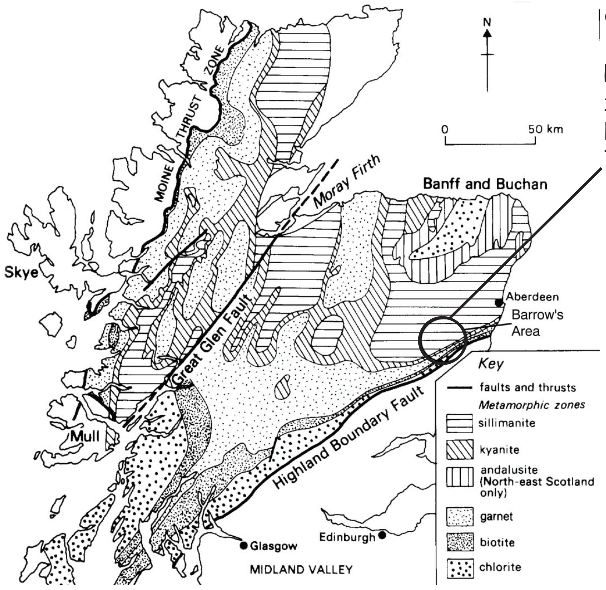
LECTURE Nineteen: Metamorphism of Pelites

IN THIS LECTURE
- Types of Protoliths
- Examples of Metamorphism
- Orogenic Metamorphism of the Scottish Highlands
- Barrovian vs Buchan Style Metamorphism
- Regional Metamorphism Otago New Zealand
- Contact Metamorphism of Pelitic Rocks

Orogenic Burial Metamorphism of the Scottish Highlands
- *Shales (pelitic) - high Al, K, Si*
- *George Barrow (1893, 1912)*
- *SE Highlands of Scotland*
- *Caledonian orogeny ~ 500 Ma (In Africa and other parts of Gondwana Pan-African Orogeny)*
- *Nappes and Granites*
- *Barrow studied the pelitic rocks*
- *Could subdivide the area into a series of metamorphic zones, each based on the appearance of a new mineral as metamorphic grade increased*



Regional metamorphic map of the Scottish Highlands, showing the zones of minerals that develop with increasing metamorphic grade. From Gillen (1982) Metamorphic Geology. An Introduction to Tectonic and Metamorphic Processes. George Allen & Unwin. London.

The sequence of zones now recognized, and the typical metamorphic mineral assemblage in each, are:
1. **Chlorite zone.** Pelitic rocks are slates or phyllites and typically contain chlorite, muscovite, quartz and albite
2. **Biotite zone.** Slates give way to phyllites and schists, with biotite, chlorite, muscovite, quartz, and albite
3. **Garnet zone.** Schists with conspicuous red almandine garnet, usually with biotite, chlorite, muscovite, quartz, and albite or oligoclase
4. **Staurolite zone.** Schists with staurolite, biotite, muscovite, quartz, garnet, and plagioclase. Some chlorite may persist
5. **Kyanite zone.** Schists with kyanite, biotite, muscovite, quartz, plagioclase, and usually garnet and staurolite
6. **Sillimanite zone.** Schists and gneisses with sillimanite, biotite, muscovite, quartz, plagioclase, garnet, and perhaps staurolite. Some kyanite may also be present (although kyanite and sillimanite are both polymorphs of Al_2SiO_5)

- Sequence = Barrovian zones
- The P-T conditions referred to as Barrovian-type metamorphism (fairly typical of many belts)
- Now extended to a much larger area of the Highlands
- Isograd = line that separates the zones (a line in the field of constant metamorphic grade)

To Summarise
- An isograd (in this classical sense) represents the first appearance of a particular metamorphic index mineral in the field as one progresses up metamorphic grade
- When one crosses an isograd, such as the biotite isograd, one enters the biotite zone
- Zones thus have the same name as the isograd that forms the low-grade boundary of that zone
- Since classic isograds are based on the first appearance of a mineral, and not its disappearance, an index mineral may still be stable in higher grade zones

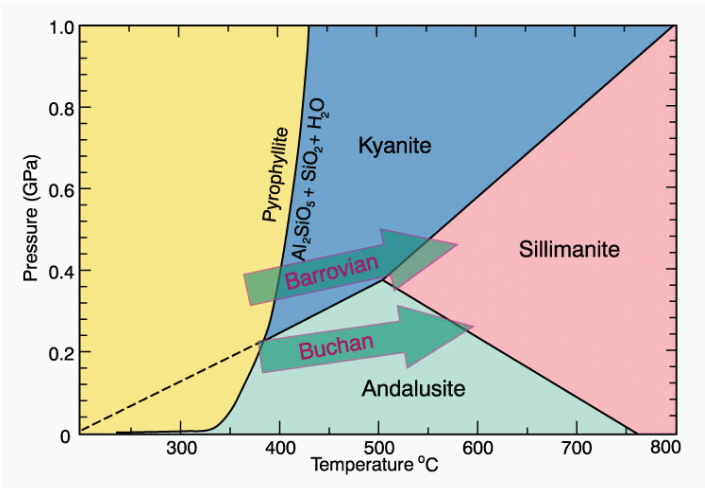
A variation occurs in the area just to the north of Barrow's, in the Banff and Buchan district
Here the pelitic compositions are similar, but the sequence of isograds is:
1. chlorite
2. biotite
3. **cordierite**
4. **andalusite**
5. sillimanite

This indicates a lower pressure version of Barrovian metamorphism called Buchan style metamorphism.

A similar variation exists for higher pressure metamorphism and to higher temperature metamorphism which results in additional zones. One of the key ways to tell which style of pelite metamorphism is to examine the development of the different aluminosilicate polymorphs.

The stability field of andalusite occurs at pressures less than 0.37 GPa (~ 10 km), while kyanite -> sillimanite at the sillimanite isograd only above this pressure

The P-T phase diagram for the system Al_2SiO_5 showing the stability fields for the three polymorphs andalusite, kyanite, and sillimanite. Also shown is the hydration of Al_2SiO_5 to pyrophyllite, which limits the occurrence of an Al_2SiO_5 polymorph at low grades in the presence of excess silica and water. The diagram was calculated using the program TWQ (Berman, 1988, 1990, 1991).



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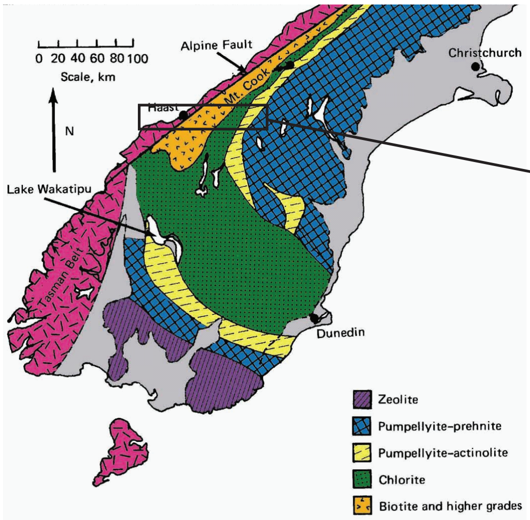
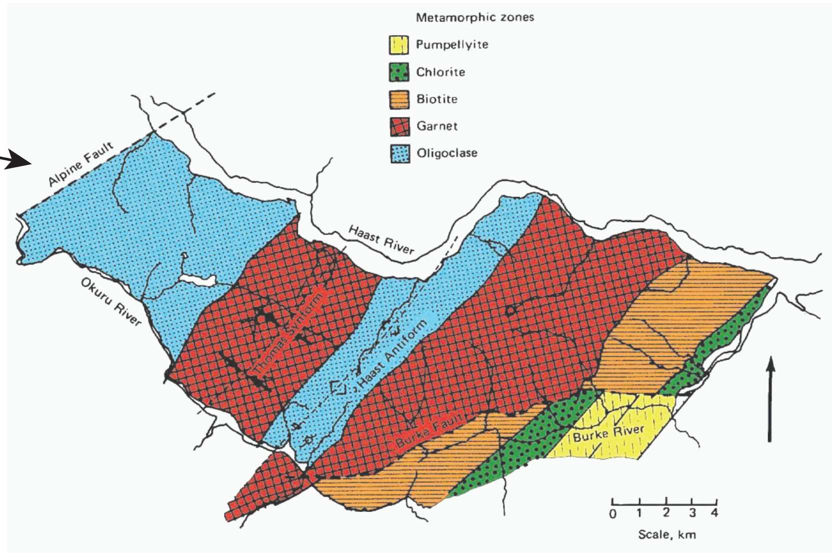
Regional Burial Metamorphism?Otago, New Zealand
- Jurassic graywackes, tuffs, and volcanics in a deep trough metamorphosed in the Cretaceous
- The fine grain size and immature nature of the material is highly susceptible to alteration, even at low grades

Geologic sketch map of the South Island of New Zealand showing the Mesozoic metamorphic rocks east of the older Tasman Belt and the Alpine Fault. The Torlese Group is metamorphosed predominantly in the prehnite-pumpellyite zone, and the Otago Schist in higher grade zones. From Turner (1981) Metamorphic Petrology: Mineralogical, Field, and Tectonic Aspects. McGraw-Hill.





Isograds mapped at the lower grades:

1) Zeolite
2) Prehnite-Pumpellyite
3) Pumpellyite (-actinolite)
4) Chlorite (-clinozoisite)
5) Biotite
6) Almandine (garnet)
7) Oligoclase (albite at lower grades is replaced by a more calcic plagioclase)

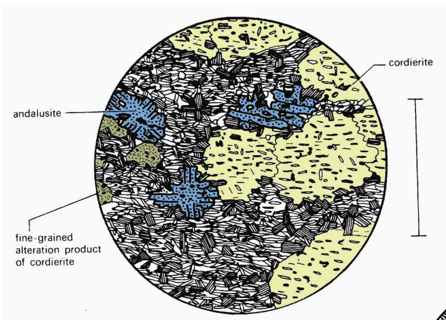
- Orogenic belts typically proceed directly from diagenesis to chlorite or biotite zones
- The development of low-grade zones in New Zealand may reflect the highly unstable nature of the tuffs and graywackes, and the availability of hot water, whereas pelitic sediments may not react until higher grades

Contact Metamorphism of Pelitic Rocks in the Skiddaw Aureole, UK

- Ordovician Skiddaw Slates (English Lake District) intruded by several granitic bodies
- Intrusions are shallow, and contact effects overprinted on an earlier low-grade regional orogenic metamorphism

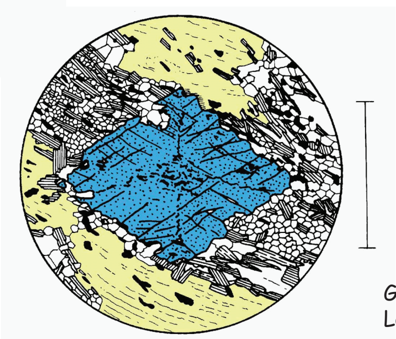
The aureole around the Skiddaw granite was sub-divided into three zones, principally on the basis of textures:

Increasing Metamorphic Grade ↓
- Unaltered slates
- Outer zone of spotted slates
- Middle zone of andalusite slates
- Inner zone of hornfels
- Skiddaw granite

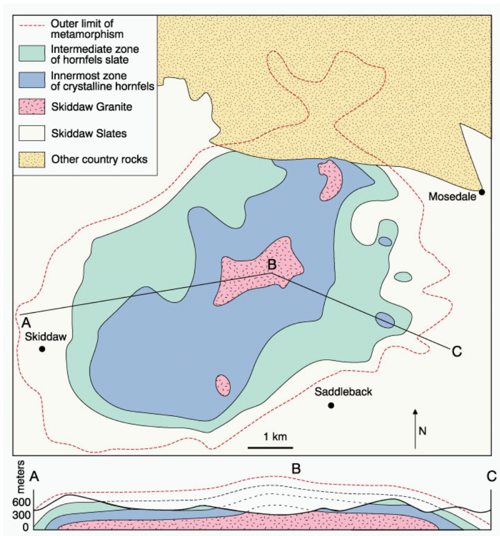


Middle zone: slates more thoroughly recrystallized, contain biotite + muscovite + cordierite + andalusite + quartz

Inner zone:
Thoroughly recrystallized
Lose foliation



The zones determined on a textural basis. Better to use the sequential appearance of minerals and isograds to define the zones. But low-P isograds converge in P-T space. Therefore, Skiddaw sequence of mineral development with grade is difficult to determine accurately



Geologic Map and cross-section of the area around the Skiddaw granite, Lake District, UK. After Eastwood et al (1968). Geology of the Country around Cockermouth and Caldbeck. Explanation accompanying the 1-inch Geological Sheet 23, New Series. Institute of Geological Sciences. London.