Contact Metamorphism
of
Pelitic Sediments

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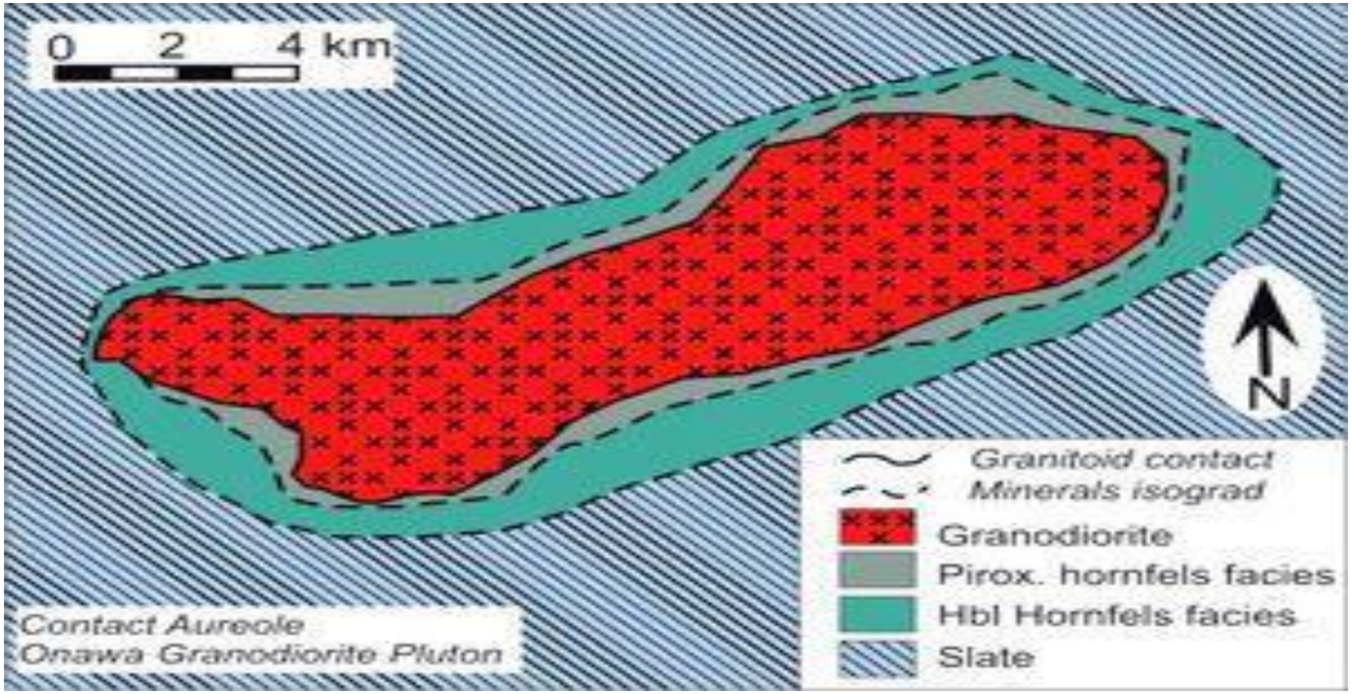
INTRODUCTION
Contact Metamorphism

- is a *Type of metamorphism of local extent that affects the country rocks around magma bodies emplaced in a variety of environments from volcanic to upper mantle depths, in both continental and oceanic settings*. The magmas are the sources of heat, mass and mechanical energy necessary for this type of metamorphism. The zone where contact metamorphism occurs is called the **contact aureole, while the products of such metamorphism are called contact rocks.**

- ***The thickness of the aureole ranges from the millimetre- to the kilometre-scale. The intensity of contact metamorphism decreases from the innermost to the outermost parts of the aureole. It is customary to separate the metamorphic effects caused by the magma on its wall rocks (exomorphism) from those induced by the wall rocks on the magma itself (endomorphism). Contact metamorphism accompanied by substantial mass transfer (change of the original rock composition) is called contact metasomatism.***

Contact metamorphism occurs as a result of a high geothermal gradient produced locally around intruding magma. Contact metamorphism is usually restricted to relatively shallow depths (low pressure) in the Earth because it is only at shallow depths where there will be a large contrast in temperature between the intruding magma and the surrounding country rock. Also, since intrusion of magma does not usually involve high differential stress, contact metamorphic rocks do not often show foliation. Instead, the common rocks types produced are fine grained idioblastic or hypidioblastic rocks called hornnfels. The area surrounding an igneous intrusion that has been metamorphosed as a result of the heat released by the magma is called a contact aureole.



Sketch map of contact metamorphism: A granite pluton intrudes a slate A concentric distribution of hornfels facies results Image Credit: MBG after Philbrick (1936) and Moore (1960)

Pelitic Sediments

- are very fine grained mature clastic sediments derived from weathering and erosion of continental crust. They Characteristically accumulate in distal portions of a wedge of sediment off the continental shelf/slope of either an active or passive continental margins.
- Pelites Grade into coarser graywackes and sandy sediments toward the continental source
- Although begin as humble mud, metapelites represent a distinguished family of metamorphic rocks, because the clays are very sensitive to variations in temperature and pressure, undergoing extensive changes in mineralogy during progressive metamorphism

Metapelites

- The mineralogy of pelitic sediments is dominated by fine Al-K-rich phyllosilicates, such as clays (montmorillonite, kaolinite, or smectite), fine white micas (sericite, paragonite, or phengite) and chlorite, all of which may occur as detrital or authigenic grains
- The phyllosilicates may compose more than 50% of the original sediment
- Fine quartz constitutes another 10-30%
- Other common constituents include feldspars (albite and K-feldspar), iron oxides and hydroxides, zeolites, carbonates, sulfides, and organic matter

Metapelites

- Distinguishing chemical characteristics: high Al_2O_3 and K_2O, and low CaO
- Reflect the high clay and mica content of the original sediment and lead to the dominance of muscovite and quartz throughout most of the range of metamorphism
- The chemical composition of pelites can be represented by the system K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O ("KFMASH")
- If we treat H_2O as mobile, the petrogenesis of pelites is represented well in AKF and A(K)FM diagrams

Metapelites

Table 28-1. Chemical Compositions* of Shales and Metapelites

	1	2	3	4	5
SiO_2	64.7	64.0	61.5	65.9	56.3
TiO_2	0.80	0.81	0.87	0.92	1.05
Al_2O_3	17.0	18.1	18.6	19.1	20.2
MgO	2.82	2.85	3.81	2.30	3.23
FeO	5.69	7.03	10.0	6.86	8.38
MnO	0.25	0.10			0.18
CaO	3.50	1.54	0.81	0.17	1.59
Na_2O	1.13	1.64	1.46	0.85	1.86
K_2O	3.96	3.86	3.02	3.88	4.15
P_2O_5	0.15	0.15			
Total	100.00	100.08	100.07	99.98	96.94

* Reported on a volatile-free basis (normalized to 100%) to aid comparison.

1. "North American Shale Composite". Gromet *et al.* (1984). **2.** Average of ~100 published shale and slate analyses (Ague, 1991). **3.** Ave. pelite-pelagic clay (Carmichael, 1989). **4.** Ave. of low-grade pelitic rocks, Littleton Fm, N.H. (Shaw, 1956). **5.** Ave. of

Contact Metamorphism of Pelitic Rocks in the Skiddaw Aureole, UK

- Ordovician Skiddaw Slates in the English Lake District are intruded by several granite and granodiorite bodies. Following a common pattern, the intrusions are shallow, and the contact effects are overprinted on an earlier phase of low-grade regional erogenic metamor-phism, during which the rocks had been metamorphosed to chlorite-zone slates.
- Outside the aureole the slates are tightly folded and typically contain muscovite (or, at these low grades, sericite-phengite), quartz, chlorite, chloritoid, and opaques (Fe-oxides, sulfides, and graphite) ± biotite.
  - The aureole around the Skiddaw granite was first described by Rastall (1910) and has been subdivided into three zones, principally on the basis of textures:

Unaltered slates

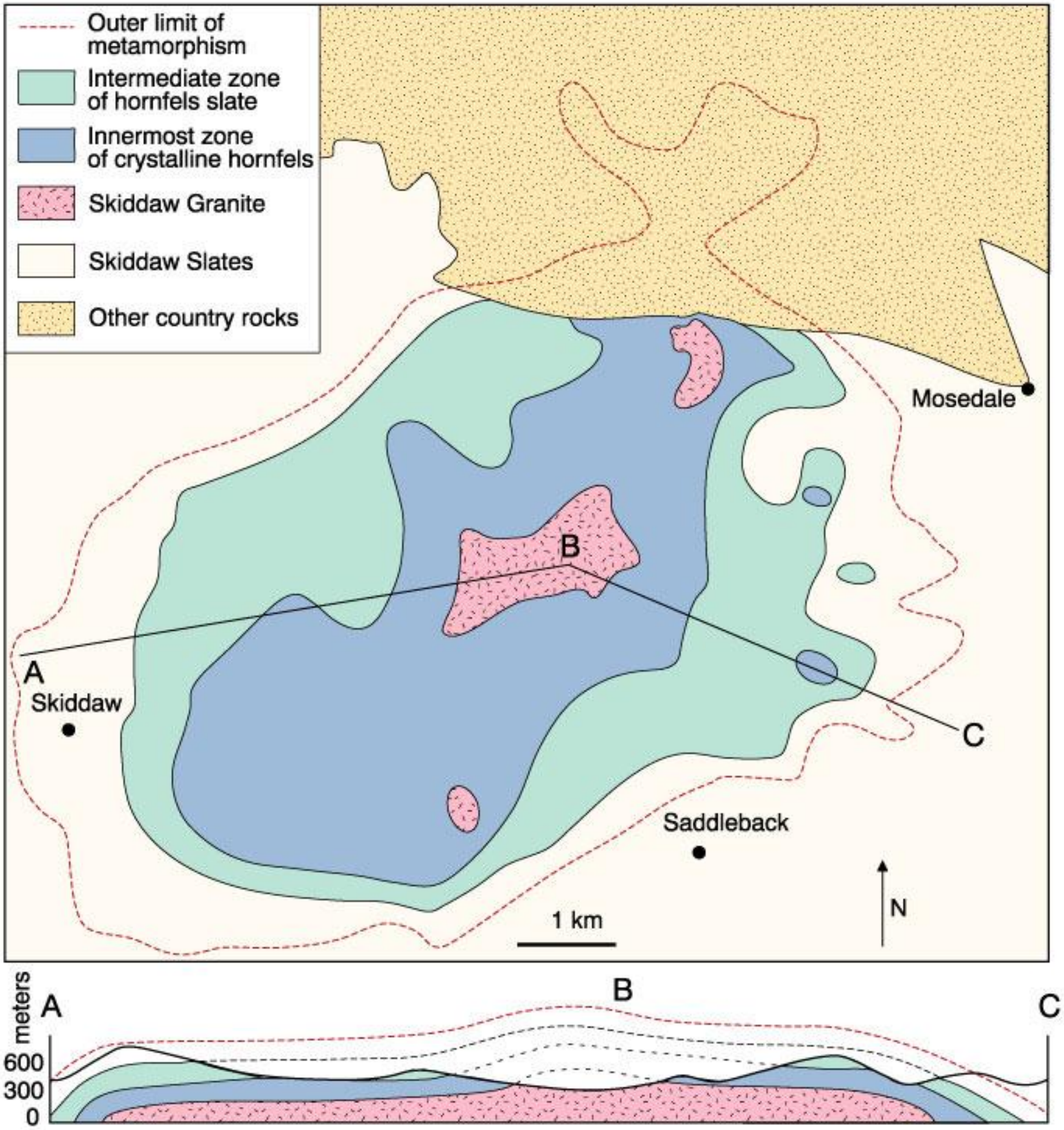
Increasing Metamorphic Grade

- Outer zone of spotted slates
- Middle zone of andalusite slates
- Inner zone of hornfels
- Skiddaw granite

Contact

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.

- First effects (1-2 km from contact) = 0.2 - 2.0 mm sized black ovoid "spots" in the slates
- At the same time, recrystallization -> slight coarsening of the grains and degradation of the slaty cleavage
- Spots were probably cordierite or andalusite, since re-hydrated and retrograded back to fine aggregates of mostly muscovite
- Both cordierite and andalusite occur at higher grades, where they are often partly retrograded, but not farther out
- Spots that we now see in most of the spotted slates are probably **pseudomorphs**



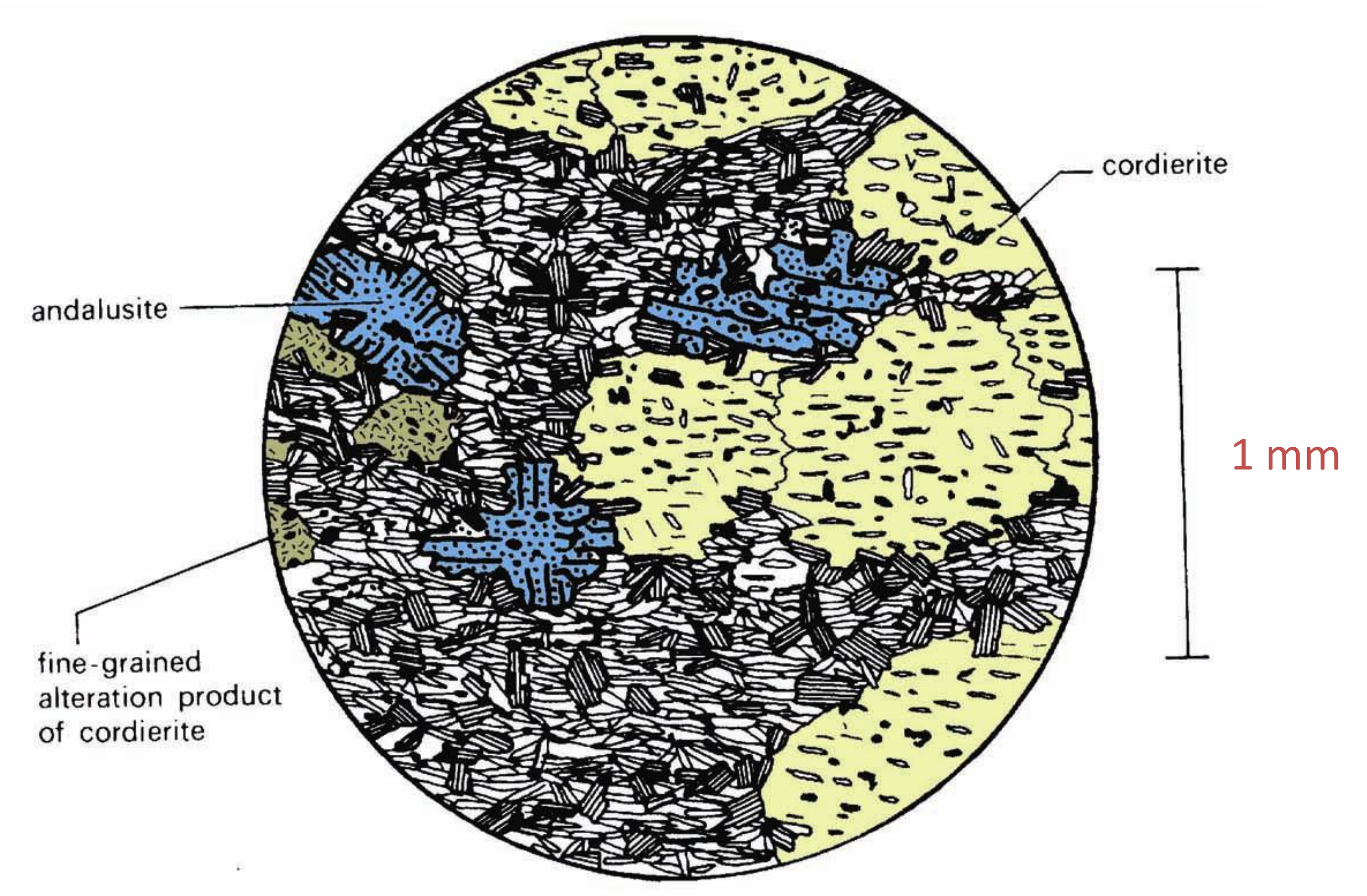
Geologic Map and cross-section of the area around the Skiddaw granite, Lake District, UK. After Eastwood et al (1968). *Geology of the Country around Cockermouth and Caldbeck*. Explanation accompanying the 1-inch Geological Sheet 23, New Series. Institute of Geological Sciences. London.

Refer: Winter,J.D.(2009). Principles of Igneous and Metamorphic Petrology, Second Edition, Pearson

Middle Zone

- Slates more thoroughly recrystallized, contain biotite + muscovite + cordierite + andalusite + quartz

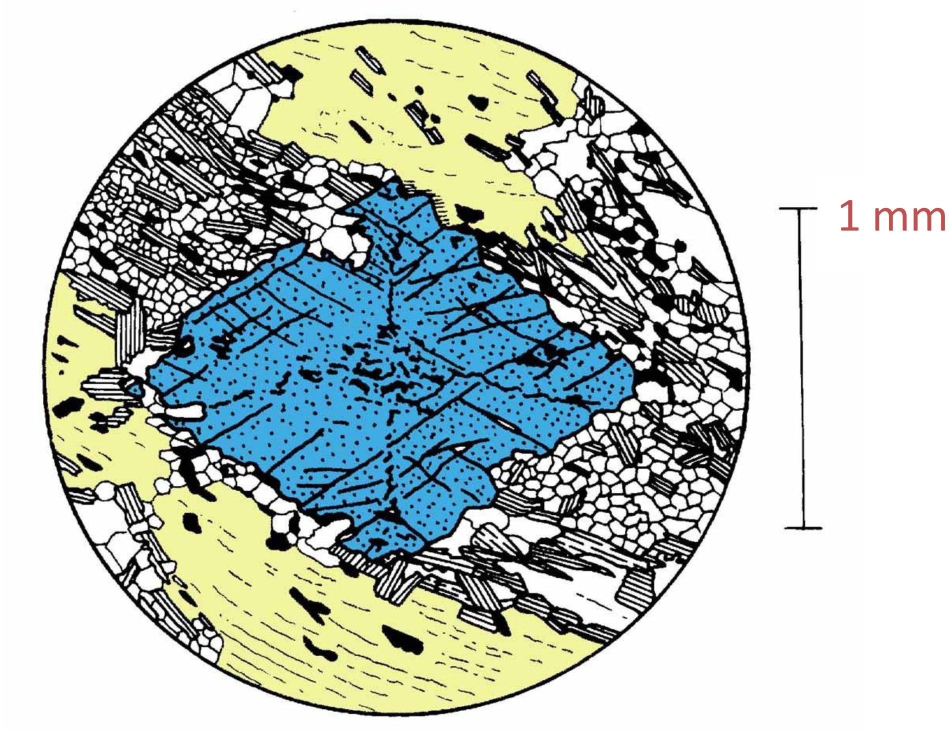
Cordierite-andalusite slate from the middle zone of th Skiddaw aureole. From Mason (1978) *Petrology of the Metamorphic Rocks*. George Allen & Unwin. London. Refer: [Winter,J.D.(2009). Principl of Igneous and Metamorphic Petrology, Second Edition, Pearson]



- Cordierite forms ovoid xls with irregular outlines and numerous inclusions, in this case of biotite, muscovite, and opaques
- The biotite and muscovite inclusions often retain the orientation of the slaty cleavage outside the cordierites
- This indicates that the growing cordierite crystals enveloped aligned micas that grew during the regional event
- Excellent textural evidence for the overprint of contact metamorphism on an earlier regional one
- Micas outside the cordierites are larger and more randomly oriented, suggesting that they formed or recrystallized during the later thermal event
- Andalusites have fewer inclusions than cordierite, and many show the cruciform pattern of fine opaque inclusions known as **chiastolite**

Inner Zone

- Both andalusite and cordierite are minerals characteristic of **low-pressure metamorphism**, which is certainly the case in the Skiddaw aureole, where heat is carried up into the shallow crust by the granites
- The rocks of the inner zone at Skiddaw are characterized by coarser and more thoroughly recrystallized textures
- Same mineral assemblage as the middle zone
- Some rocks are schistose, but in the innermost portions the rock fabric loses the foliation, and the rocks are typical **hornfelses**



Andalusite-cordierite schist from the inner zone of the Skiddaw aureole. Note the chiastolite cross in andalusite (see also Figure 22-49). From Mason (1978) *Petrology of the Metamorphic Rocks*. George Allen & Unwin. London. Refer: Winter,J.D.(2009). Principles of Igneous and Metamorphic Petrology, Second Edition, Pearson

Important Points to Understand

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

- A more modern approach conform to the regional example above, and **use sequential appearance of minerals and isograds** to define the zones
- First new mineral in most slates is **biotite**, followed by the approximately simultaneous development of **cordierite** and **andalusite**
- Perhaps the textural zonation is more useful in some cases.
- In the inner aureole at Comrie (a diorite intruded into the Dalradian schists back up north in Scotland), the intrusion was hotter and the rocks were metamorphosed to higher grades than at Skiddaw.
- **Orthopyroxene** occurs in pelitic and quartzo-feldspathic rocks only at the very highest grades of contact and regional metamorphism, grades that may not be reached prior to melting in many instances
- Typical mineral assemblages = hypersthene + cordierite + orthoclase + biotite + opaques

Some very interesting **silica-undersaturated** rocks also occur in the inner aureole

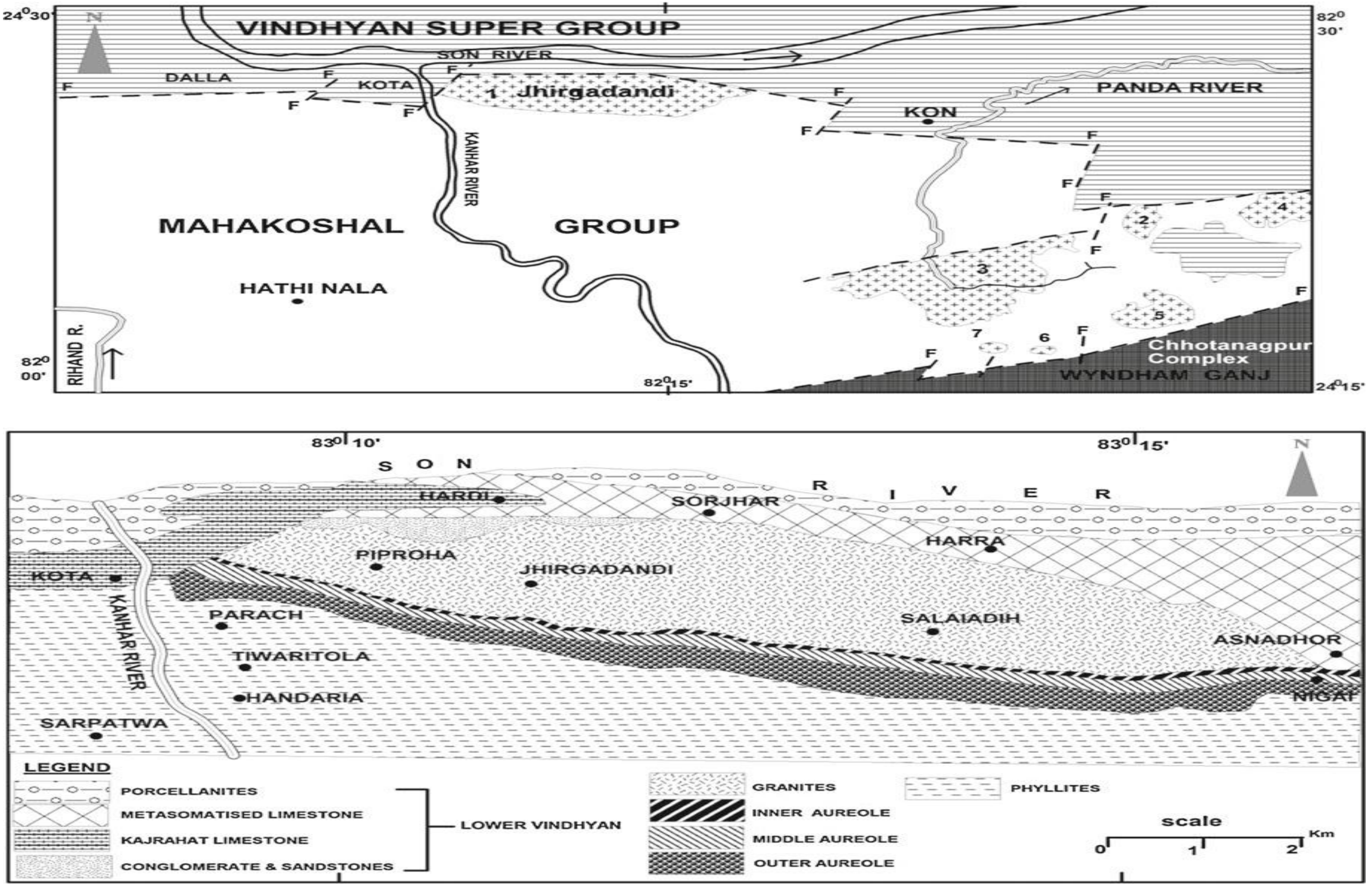
  - Contain such non-silicate high-temperature phases as **corundum** and Fe-Mg **spinel**
  - Tilley noted that the low-silica rocks occur only in the inner aureole, and attributed their origin to loss of SiO_2 into the diorite
  - Better explanation is that SiO_2 (and H_2O) were **scavenged by granitic partial melts** formed in the sediments adjacent to the contact with the hot diorite

Metamorphic evolution of the contact aureole of the Jhirgadandi pluton, Sonbhadra district, Mahakoshal mobile belt, central India*

- The metamorphic evolution of the contact aureole around the Late Paleoproterozoic Jhirgadandi pluton in the eastern part of Parsoi Formation of Mahakoshal terrain, central India represents three distinct metamorphic zones, characterized by definite mineral assemblages.
- The contact-metamorphic event produced the peak-metamorphic mineral assemblages Bt + Qtz + Alb + Sil ± *Cd* ± *Grt* ± *Mus* ± *Kfs in the* metapelites of inner aureole, Bt + Qtz + And + Mus + Kfs + Plag ± *Cd* ± *Chl in middle aureole and* Chl + Mus + Bt ± *And + Alb + Qtz* ± *Ep + Mt* ± *tourmaline in the outer aureole. The estimated P–T* conditions based on detailed geothermobarometric calculations in the thermal metamorphosed rocks are 690◦*C/3.4 kbar, 580 ± 15◦C and 487 ± 30◦C in inner aureole, middle aureole and outer aureole, respectively.*

- The variation in metamorphic condition suggests that the shallow crustal level emplacement of Jhirgadandi pluton is responsible for the overprinting of contact metamorphic assemblages (M2) in the low grade metapelites (regional metamorphism M1) of Mahakoshal Group.

* S P Singh et al.(2013).Metamorphic evolution of the contact aureole of the Jhirgadandi pluton, Sonbhadra district, Mahakoshal mobile belt, central India;*Journal of Earth System Sciences* **volume 122**, pages743–757.



(a) Geological map of the eastern part of Parsoi Formation of Mahakoshal Group showing series of granitoid intrusives, marked by numbers. 1=Jhirgadandi, 2=Baghisoti, 3=Tumia, 4=Rohiniyan, 5=Kumba Khurd, 6=Harnakachar (Kon road) and 7=Harnakachar. (b) Geological map around Jhirgadandi showing the three zones of contact aureole at the southern part of Jhirgadandi pluton (modified after Srivastava 1977).

Jhirgadandi aureole

- The thermal aureole of the Jhirgadandi pluton is about 600 m wide . The metamorphic rocks in the aureole are mainly metapelites with layers of metapsammites of several mm to cm thickness. Based on the textural and mineralogical associations the aureole has been divided into three parts, viz., inner, middle and outer aureoles/*zones*.
- Relics of sedimentary textures are nearly absent in the inner aureole and occasionally preserved in the middle and frequently observed in outer aureole.

Country rocks outside the contact aureole

- In general, the Parsoi Formation is characterized by low-grade tuffaceous phyllite and metasediments of green-schist facies, occupying the large area between Jhirgadandi to Renukoot of Son valley (Nair *et al. 1995; Roy et al. 2002).*
- *Metasediments* contain white mica (sericite), chlorite, quartz, albite and sometimes graphite.
- A metamorphic mineral association of metavolcanics consists chlorite + actinolite + albite + epidote ± *quartz* ± white mica ± *prehnite* ± *calcite* ± *biotite* ± *titanite* ± *ilmenite* ± *magnetite (Nair et al. 1995).*

Rocks in the contact aureole

- The progressive thermal metamorphism of the metapelites with pre-exiting foliation resulted in a steady decrease of fissility as the grade progresses. The Jhirgadandi aureole constitutes three distinct zones of aureoles, each characterized by specific mineral assemblages and textural and structural characteristics (Srivastava 1969; Kumar 2005). The inner aureole with immediate contact with granite is characterised by high temperature minerals such as fibrolite, cordierite and garnet. The transition to the middle aureole, biotite and andalusite exhibit random orientation and decussate texture and the outer aureole have medium to fine
- The **inner aureole** is between 25 and 50 m in width and lies in the immediate neighbourhood of Jhirgadandi pluton. At the immediate contact the mineralogical changes become too frequent and within a short distance the rock show dominance of garnet and fibrolite and are characterized by hornfelsic texture . Cordierite and red coloured biotite are the important minerals present. The muscovite is nearly absent and decomposed into fibrolite which demarcates the beginning of this zone.

The outer boundary of the **middle aureole** is characterized by decussate and sporadic granoblastic texture. The andalusite, muscovite and biotite are usually represented by the random orientation and chlorite is nearly absent. The andalusitemuscovite-biotite *± cordierite-quartz is the prominent* mineral assemblages in the pelitic rocks of this zone.

- The peripheral part(**outer aureole**) of the aureole comprises mainly of phyllitic rocks with spotted appearance. The rocks are less fissile relative to the country rock. Chlorite, muscovite, biotite, sericite, ilmenite, albite, microcline, andalusite and tourmaline are the important minerals representing this zone. The first mineralogical changes are typified by the segregation of the clay minerals into shimmer aggregate and partial conversion of chlorite into biotite.

Exercise

1. How will you identify the terrain which is metamorphosed by contact metamorphism?
2. Discuss the contact metamorphism of pelitic sediments.

References :

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2. Winter,J.D.(2009). Principles of Igneous and Metamorphic Petrology, Second Edition, Pearson

3. An Introduction to Metamorphic Petrology by Bruce Yardley

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5. S P Singh et al.(2013).Metamorphic evolution of the contact aureole of the Jhirgadandi pluton, Sonbhadra district, Mahakoshal mobile belt, central India;*Journal of Earth System Sciences* **volume 122**, pages743–757.

6. https://www.bgs.ac.uk/downloads/start.cfm?id=3194

THANKS