Examination of the Sanidinite Facies with Examples from Localities in Iran, Turkey and North America

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Abstract

The sanidinite metamorphic facies is associated with very high temperature and low pressure conditions. They are most typically found in contact aureoles near surface, although relative to other metamorphic rocks, sanidinite facies are not volumetrically abundant. It is because of these reasons and more that they are not often discussed in petrologic textbooks and when discussed in studies, they are only briefly discussed. In this report, the sanidinite facies is discussed in detail regarding its history, occurrence and its common mineral assemblages. Three case studies that were shown to involve rocks that experienced conditions that of sanidinite facies are discussed herein.

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1. Introduction

The sanidinite metamorphic facies is the high temperature end-member observed in contact metamorphism. Literature regarding the sanidinite facies has been available since it was first described in the nineteenth century. However, many modern petrology textbooks offer minimal information regarding the sanidinite facies; this is likely due to the fact that metamorphic rocks exposed to these conditions are exceptionally rare and volumetrically insignificant and (Grapes, 2011). The purpose of this report is to provide a detailed description on the particular characteristics found in sanidinite facies metamorphic rocks. It will first describe the conditions required for rocks to occur. Then it will describe where they may be found regionally and typical mineral assemblages and chemical reactions that are associated with the development of these rocks. Finally, this report will briefly look at three case studies from Turkey, Iran and North America where rocks were exhibited to sanidinite facies conditions.

2. Definition

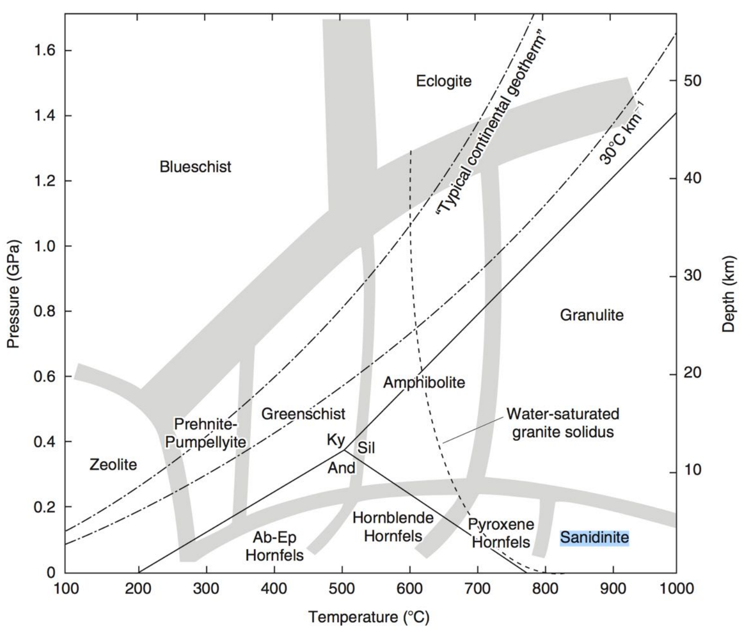

Figure 2.1 – Metamorphic facies graph showing the stability range of each of the described facies. These are compared by both pressure (measured in GPa) and depth (in km) on the vertical axis and increasing temperature (in ºC) on the horizontal axis. The occurrence of sanidinite facies is highlighted on the bottom right of the diagram (Kearey *et al.*, 2009).

Sanidinite is named after sanidine, the high temperature form of potassium feldspar. Brauns (1912) first used the term sanidinite was first used to describe sanidine-rich xenoliths that occurred in volcanic rocks (Grapes, 2011). Eskola (1920) later adopted the term to represent his highest temperature, lowest pressure member of his original five metamorphic facies (Winter, 2010). Sanidinite facies are often characterized from other facies by their compositions, textures (which range from partially melted to massive), crystal habit, pyrometamorphic mineral assemblages and the preservation of glass.

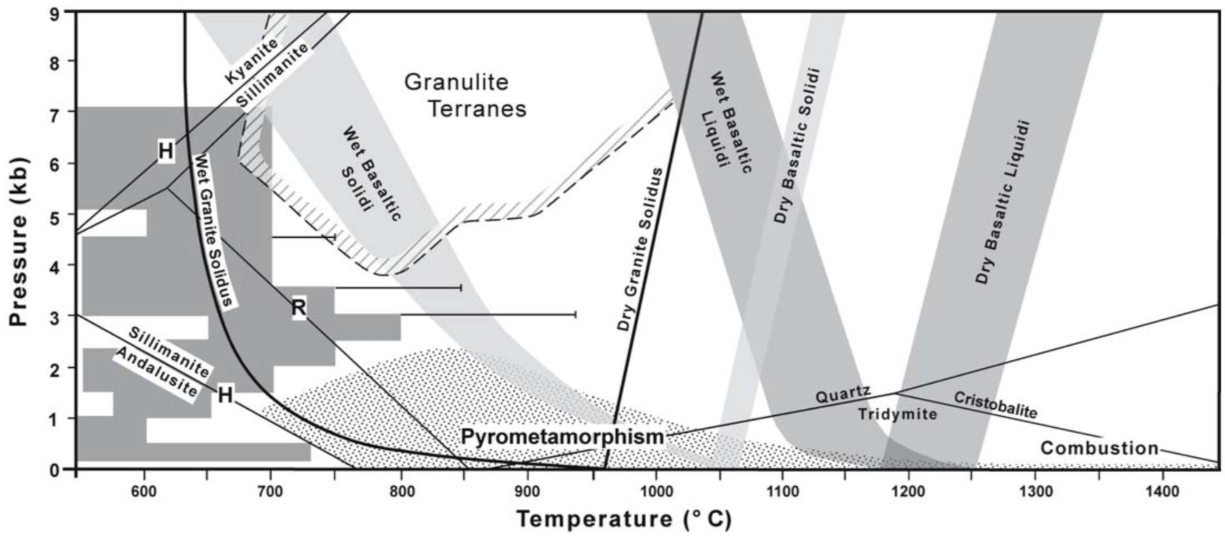

Figure 2.2 – Diagram showing the sanidinite facies stability field and the relationship of sanidinite facies rocks (*stippled area*) to contact metamorphic and granulite facies rocks. (Grapes, 2011).

Sanidinite facies rocks are the result of pyrometamorphism, which is metamorphism by the action of heat, with little or no influence by pressures and active fluids such as water and CO_2 (Fyfe *et al*., 1958). Thereby, temperature conditions observe in the sanidinite facies exceeds 600ºC and experiences pressures typically less than 3 kbar (Fyfe *et al*., 1958). Figure 2.1 shows the stability range of the sanidinite facies the metamorphic facies petrographic grid. As can be discerned, depths are shallow and under approximately 8 km. Figure 2.2 shows more specifically, the sanidinite facies stability field in relation to contact metamorphic rocks (albite-epidote hornfels, hornblende hornfels and pyroxene hornfels, which similar to sanidinite facies experience low pressures and high temperatures) and the granulite facies rocks (high grade metamorphic rocks that rocks experience high temperatures and medium to high pressures) (Grapes, 2011).

Sanidinite facies are distinguished from pyroxene hornfels at low pressures by the absence of andalusite and pyralspite garnet in quartzofeldspathic rocks and grossular garnet in calc-silicate rocks (Grapes, 2011). The formation of monticellite from diopside and forsterite indicates the transition from pyroxene hornfels to sanidinite facies in silica-poor calcareous rocks (Grapes, 2011). Distinction from mafic and ultramafic rocks is difficult (Grapes, 2011).

3. Occurrence

Metamorphic rocks exposed to sanidinite facies conditions can be found in several places. They can be found in contact aureoles located in shallow basaltic intrusions (Grapes, 2011). Here they are typically restricted to xenoliths (Fyfe et al., 1958). Figure 3.1 shows the evolution of xenolith development. When nearby magma causes rock temperatures to reach values where melting can occur, the rigidity and mechanical integrity of the rock is significantly reduced and unstable portions in the wall rocks can become dislodged and appropriated into the magma where recrystallization may proceed (Grapes, 2011). They also occur in sediments that overlay burnt coal seams and in combusted carbonaceous sediments (Grapes, 2011).

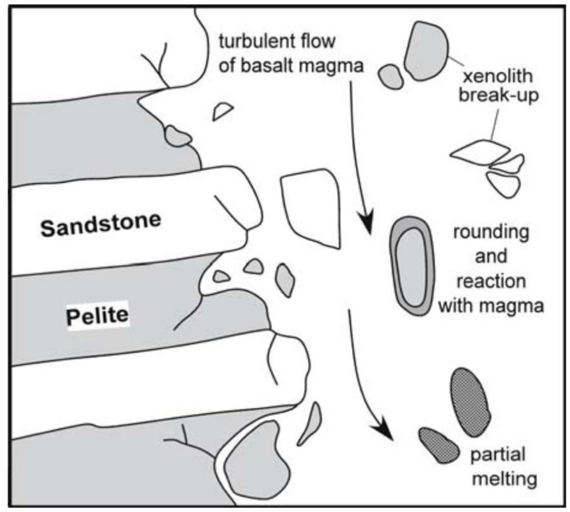

Figure 3.1 – Diagram showing formation and evolution of xenoliths (Grapes, 2011)

4. Mineral Assemblages

Despite its name, sanidinite facies mineral assemblages often do not contain sanidine. The following section looks at typical mineral assemblages associated with calcarious, pelitic, quartzofeldspathic, basic and ultramafic protoliths. These are primarily based on the work by Eskola (1939).

4.1 Pelitic mineral assemblages

Typical mineral assemblages associated with pelitic protoliths include:

- tridymite-cordierite-mullite ± glass
- anorthite-corundum-spinel
- cordierite-spinel-mullite ± glass

4.2 Quartzofeldspathic mineral assemblages

According to Grapes (2011), typical mineral assemblages for pyrometamorphosed rocks with quartzofeldspathic (sandstone, shale, mudstone) protoliths are based off of Eskola (1939) and include:

- tridymite-sanidine-glass
- anorthite-cordierite-mullite
- anorthite-clinopyroxene-orthopyroxene
- anorthite-cordierite-orthopyroxene
- cordierite-orthopyroxene

- corundum-mullite-spinel
- cordierite-mullite-spinel
- cordierite-mullite-tridymite

4.3 Calcareous mineral assemblages

Fyfe *et al.* (1958) propose that sanidinite mineral assemblages with calcareous protoliths can be subdivided by their stability at different temperatures. These include assemblages capable of withstanding all temperature ranges, assemblages stable only in relatively lower temperature ranges, and those that are stable in higher temperature ranges. Specific ranges are not given. These assemblages are summarized below in Table 4.1.1.

Table 4.3.1 – Mineral assemblage for sanidinite facies from calcareous protoliths

All Temperatures	Lower temperatures only:	Higher temperatures only
anorthite-wollastone ± diopside ± tridymite	wollastonite-melilite-calcite	wollastonite-rankinite-melilite
wollastone-diopside-tridymite	monticellite-melilite-calcite	rankinite-melilite-larnite
diopside-wollastonite-melilite	forsterite-monticellite-calcite	melilite-larnite-merwinite
diopside-monticellite-melilite	forsterite-periclase-calcite	melilite-merwinite-monticellite
		larnite-merwinite-spurrite
		merwinite-spurrite-calcite
		merwinite-monticellite-calcite
		monticellite-periclase-calcite

4.4 Basic mineral assemblages

Fyfe *et al*. (1958) provide only one basic derived sanidinite mineral assemblage: plagioclase-diopside-hyperthene (or clinohyperthene).

4.5 Magnesian mineral assemblages

Pyrometamorphosed aluminous magnesian-rich (ultramafic) are exceptionally rare (Grapes, 2011). They can only be mineralogically distinguished from pyroxene-hornfells by the presence of cordierite (Grapes, 2011). The mineral assemblage includes the following:

- enstatite-tridymite ± cordierite
- forsterite-periclase ± spinel
- forsterite-cordierite ± spinel
- forsterite-enstatite ± cordierite

4.6 Preservation of glass

The preservation of glass is somewhat unique in sanidinite facies and its presence is notable. Figure 4.6.1 shows a relationship between temperature and enthalpy in a system. Above the 'glass transformation temperature,' shows the effects of temperature on the volume of a glass-forming melt. Above the 'glass transformation temperature,' which is a temperature dependent on cooling rate over which melt becomes solid (glass), supercooled liquids are stable (Grapes, 2011). Below the 'glass transformation temperature,' glass is stable (Grapes, 2011). Glass will only crystallized if they experience temperature conditions above the 'glass transformation temperature' of a period of time (Grapes, 2011).

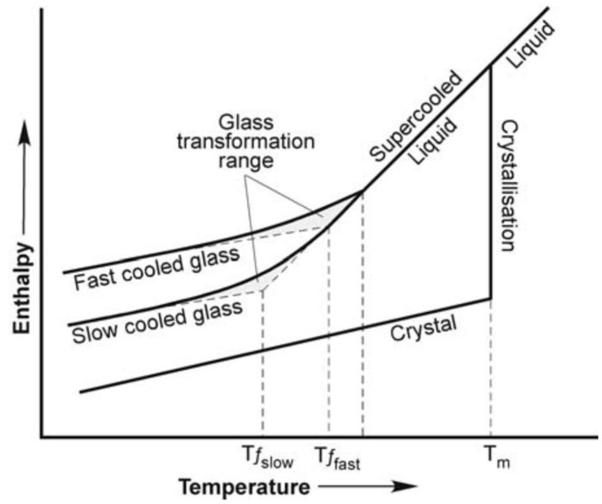

Figure 4.6.1 – Diagram illustrating the effect of temperature on the enthalpy of a glass-forming melt (Grapes, 2011).

5. Case Studies

For this report, three studies that featured high-grade contact metamorphism within the sanidinite facies were examined and will be briefly summarized in the following section.

5.1 Contact Alteration in Gabbroic Wall Rock in southern Maine

Woodard (1968) examined rocks along a northern contact of the Cape Neddick Gabbro from Maine, United States, that demonstrated that a reaction had occurred between the Kittery Formation and adjacent gabbro resulting in grossly alteration by thermal metamorphism. The purpose of his research was to describe the mineralogical and chemical aspects of these reactions caused by contact metamorphism and determine the origin of the rock types he observed. Among these rocks, he observed a zone of sanidinite facies metamorphism that extended outwards from the contact for at least 24 m. Woodard (1968) indicates that the development of the sanidinite facies throughout the zone occurred with fluid pressures less then 1 kbar and temperatures of roughly 800ºC.

5.2 Alvand contact Aureoles in Western Iran

Migmatites that bordered granitic intrusions were studied by Saki *et al*. (2012) and were found to comprise substantial, high-grade metamorphic part of the Alvand aureole near Hamadan, western Iran. Figure 5.2.1 shows the area of study. These were determined to be comprised of metamorphosed pelitic rocks. Some contacts were on the low end of the sanidinite facies on the transition from the pyroxene hornfels facies. The occurrence of sanidinite facies is marked by the occurrence of orthopyroxene. Peak metamorphism conditions in the migmatites took place around 650 to 750ºC with pressures between 2 and 4 kbar.

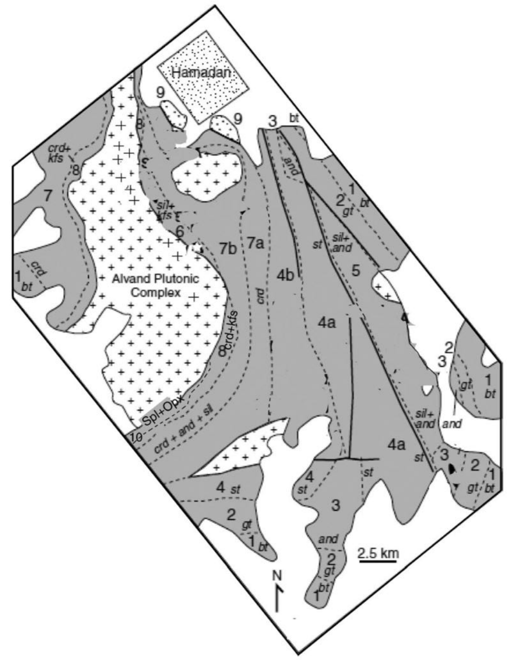

Figure 5.2.1 – Geological map of the study area near Hamadan. Isograds (dashed lines) and metamorphic zones are shown. Contacts between zones 4a and 4b, 4a and 5, 2 and 5, and possibly 4 and 7 are faults. Zones: 1, biotite zone; 2, garnet zone; 3, andalusite zone (± fibrolite); 4, staurolite zone (a, staurolite + andalusite ± fibrolite; b, staurolite + garnet, no andalusite); 5, sillimanite–andalusite zone; 6, sillimanite–Kfs zone; 7, cordierite zone (a, cordierite with no new growth of $Al_2 SiO_5$ polymorph; b, cordierite + neoblastic andalusite + sillimanite); 8, cordierite + Kfs zone; 9, spotted schist; 10, spinel + orthopyroxene zone (migmatites) (Saki *et al*., 2012).

5.3 High Temperature Skarns in Güneyce–Ikizdere Area, Turkey

Taner *et al*. (2013) examined the presence of high-temperature, low-pressure contact metamorphic assemblages, with in the Güneyce–Ikizdere area, eastern Black Sea, Turkey, some belonging to the sanidinite facies. Figure 5.2.1 shows a generalized geologic map of the study area. These were caused by the emplacement of plutonic rocks of the calc-alkaline Rize batholith which lead to mineral assemblages typical of spurrite-merwinite subfacies.

Metamorphism of siliceous limestone that were subjected to physical conditions belonging to the sanidinite facies resulted in the formation of rankinite, tilleyite, larnite and spurrite and wollastonite. Figure 5.3.2 shows a thin section that is primarily monomineralic containing spurrite that associated with sanidinite facies. It is believed that the temperature conditions that were present were in the range of 800 to 850ºC. These unusually high temperatures that are adjacent to compositionally intermediate magma are believed to reflect the presence of underplating of basic magma, as well as efficient transfer of heat by the rising fluid phase.

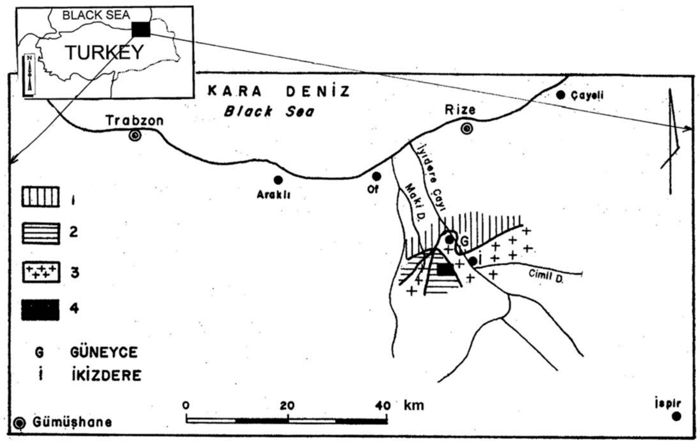

Figure 5.3.1 – Location of the study area, south of the Black Sea in eastern Turkey. Legend: 1 Upper Cretaceous sedimentary and volcanic sequences; 2 Lower Cretaceous sedimentary sequences, dominantly carbonates; 3 plutonic rocks of the Rize batholith, of intermediate to felsic composition; 4 spurrite–tilleyite-bearing skarn zones. (Taner *et al*., 2013).

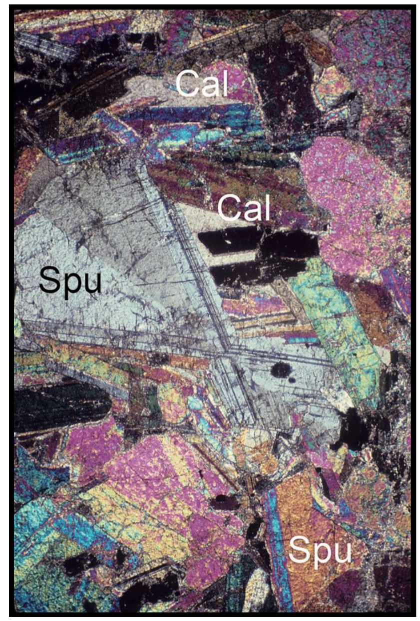

Figure 5.3.2 – Crystals of spurrite (Spu), showing polysynthetic twins with calcite (Cal). in a rock that is essentially monomineralic. Viewed with crossed polars and a width of field of view is 1.65 cm. (Taner *et al*., 2013).

7. Conclusions

1. The sanidinite facies is a high temperature, low pressure metamorphic stability field that occurs at temperatures greater than approximately 800ºC and pressures under 3 kbar.

2. Rocks of these physical conditions are rare and are not volumetrically significant relative to other metamorphic facies and is therefore not often discussed in detail in many petrologic textbooks.

3. They most often occur in contact aureoles around basaltic magmas near the surface, and commonly are associated with xenoliths. They can also arise due to combustion of coal seams, carbonic sediments or hydrocarbon deposits.

4. Three case studies were discussed showing a variety of sanidinite facies occurrences.

7. References

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