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FLUID-ABSENT METAMORPHISM IN THE ADIRONDACKS.

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Introduction. Granulite facies metamorphism occurred over an area of > 20,000 km^2 in the Adirondack Highlands, N.Y., USA and has been dated at ~ 1.1 by. (Grenville Orogeny, ref. 1). Peak metamorphic conditions as determined from numerous geothermometers and barometers in many rock types increase from about 675° at the orthopyroxene isograd in the NW to 775°C in the Central Adirondacks at 7.6 ± 0.5 kbar (Fig. 1, ref. 2). Low values of water activity (αH_2O) are demonstrated by assemblages of tremolite + diopside + enstatite + quartz; phlogopite + quartz + enstatite + K-feldspar; annite + K-feldspar + magnetite + ilmenite; and unmelted K-feldspar + plagioclase + quartz. Quantitative estimates from mica and amphibole equilibria yield $\alpha H_2O \approx 0.1$ (3,4,5). Muscovite + quartz assemblages in adjacent amphibolite facies rocks in the NW Adirondack Lowlands indicate high αH_2O demonstrating that the amphibolite to granulite facies transition in the Adirondacks is the result of increasing temperature and decreasing αH_2O.

Causes of low α H_2O. Three processes can account for low α H_2O in granulites: A) large amounts of CO_2 infiltration where H_2O-rich fluids are diluted by CO_2 and dehydration reactions for mica and amphibole are driven in the prograde direction (6); B) partial melting with or without the extraction of a magma and where H_2O is partitioned preferentially into the silicate liquid (7); and C) metamorphism of igneous or metamorphic rocks that were already "dry."

The recognition that one of these processes has influenced the formation of a given rock is important in understanding its history because the results of each process can be quite different. Only processes A) and B) can result in large amounts of mass transport such as is necessary to dehydrate a metasediment or cause LIL element depletions. Processes B and C on the other hand can lead to a metamorphic recrystallization in the absence of a free fluid phase where any hydrogen or carbon that may be in a rock during metamorphism is not in the form of an H_2O - CO_2 fluid. CO_2 infiltration, process A, cannot proceed under fluid-absent conditions.

Fluid-absent metamorphism. Fluid-absence has thus far been demonstrated in two rock types in the Adirondacks. In calc-silicates and marbles adjacent to massif-type anorthosite bodies low values of $\delta^{18}O$ (-1.3 to 3) indicate that low P contact metamorphism preceded granulite metamorphism (8,9). In these rocks numerous wollastonite occurrences indicate low αCO_2 and in one rock the assemblage monticellite + forsterite + diopside + calcite + spinel indicates $P\ H_2O + P\ CO_2 < 0.5$ kbar at P = 7.5 kbar (Fig. 2). These results, plus the close preservation of pre-regional metamorphic $\delta^{18}O$ values, indicate that granulite facies metamorphism was representative of process C where early shallow contact metamorphism volatilized marbles and subsequent granulite metamorphism was fluid-absent.

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Many charnockites in the Adirondacks are also indicated to have been fluid-absent by low, buffered values of oxygen fugacity (fO_2) and water fugacity (fH_2O, ie αH_2O). Estimates of fO_2 in Adirondack charnockites from coexisting magnetite + ilmenite (10) are mostly below the quartz + magnetite + fayalite buffer (Fig. 3) and are too low for the stable existence of a CO_2-rich metamorphic fluid (Fig. 4). These rocks typically contain orthopyroxene + K-feldspar assemblages which also indicate low fH_2O. Simultaneous solution of C-O-H fluid equations show that at such low fO_2 and low fH_2O there cannot have been a free C-O-H fluid phase and thus metamorphism was fluid-absent in these rocks (11). Many of these charnockites are clearly indicated by field relations, textures, and geochemistry to be meta-igneous rocks and thus it is reasonable that they experienced fluid-absent metamorphism because they were already "dry." However, this has not been demonstrated in all instances and significant partial melting is likely to also be important.

Recognition of fluid-absence in some Adirondack rocks does not necessarily imply that this entire former portion of the deep crust was lacking in fluids. Assemblages of phlogopite + calcite + quartz and tremolite + calcite + quartz are common and at Adirondack P-T this requires $P\ H_2O + P\ CO_2 \approx$ 6-8 kbar (12) suggesting fluid saturation.

This result in no way conflicts with fluid-absence for other rocks if the fluid regime of the deep crust is complex. Sharp gradients in $\delta^{18}O$ and in buffered fluid compositions (3,8) indicate that fluid conditions in the Adirondacks were locally heterogeneous. Thus it is likely that processes B, C, and possibly A all operated synchronously and possibly in close proximity. However, no evidence of large scale CO_2 infiltration has yet been found in the Adirondacks and even in terranes where strong evidence of CO_2 infiltration has been located in some rocks (6) it is premature to assume that all rocks were affected.

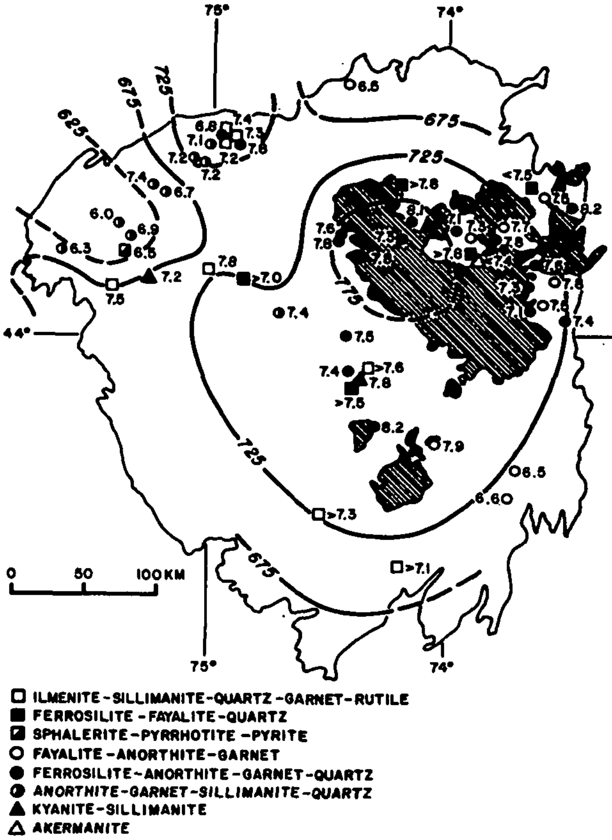

Figure 1. Values of peak metamorphic pressure and temperature in the Adirondacks (ref. 2).

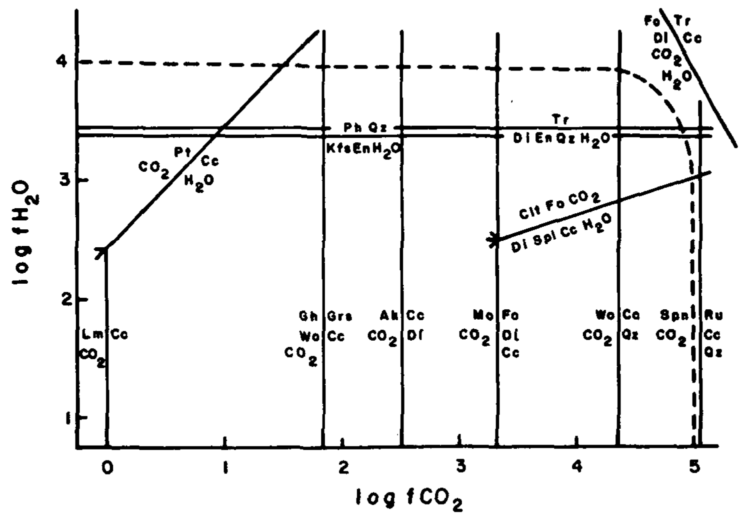

Figure 2. Mineral equilibria buffering fCO_2 and fH_2O at 780°C and 8 kbar. The dashed curve represents P H_2O + P CO_2 = 8 kbar and fluid-absent conditions plot below or to the left. The fluid-absent assemblage monticellite + forsterite + diopside + calcite + spinel plots at log fCO_2 = 3.3, log fH_2O < 2.5 (ref. 9).

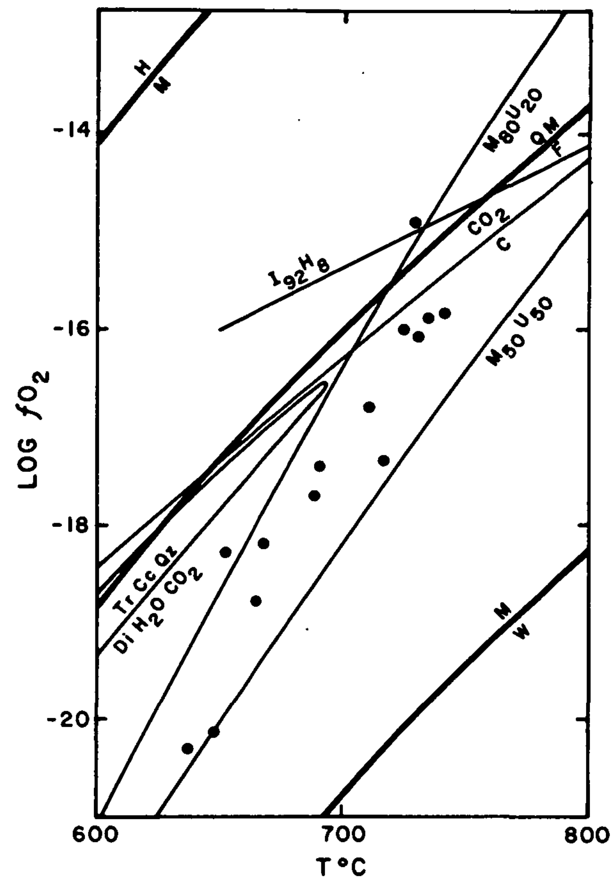

Figure 3. Log fO_2 - T plot at 8 kbar. Data points are from coexisting magnetite + ilmenite (10,13). Abbreviations are: H hematite, Q quartz, M magnetite, F fayalite, U ulvospinel, I ilmenite, W wustite, C graphite, Tr tremolite, Cc calcite, Di diopside.

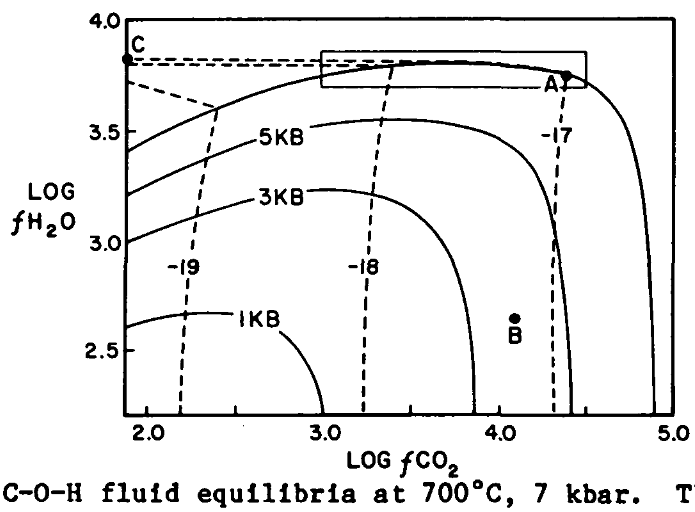

Figure 4. C-O-H fluid equilibria at 700°C, 7 kbar. The outermost curved solid line represents graphite saturation at P_{fluid} = 7 kbar. Solid isopleths below this curve are the maximum total pressure of all C-O-H fluids possible regardless of the presence or absence of graphite and thus the field below graphite saturation represents fluid-absence unless large amounts of some non C-O-H fluid are present (ref. 11).

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