DOWNLOAD PDF HIGH-TEMPERATURE METAMORPHISM OF PLUTONIC ROCKS FROM THE MID-CAYMAN RISE

Chapter 1 : Metamorphic rock - Regional metamorphism | calendrierdelascience.com

High-temperature metamorphism of plutonic rocks from the Mid-Cayman Rise: a petrographic and oxygen isotopic study /.

Protolith was limestone or dolostone c. Composed essentially of calcite crystals d. Used to create monuments and statues e. Exhibits a variety of colors resulting from impurities 2. Formed from quartz sandstone b. Quartz grains are fused 3. Banding is relict bedding, not foliation V. Contact or thermal metamorphism 1. Occurs due to a rise in temperature when magma invades a host rock 2. Zone of alteration called a contact aureole forms in the rock that surrounds the emplaced magma a. Mineral composition of the host rock and the availability of water affect the size of the aureole produced b. Large aureoles often consist of distinct zones of metamorphism 3. Most easily recognized when it occurs at the surface, or in a near-surface environment B. Chemical alteration caused when hot, ion-rich fluids, called hydrothermal solutions, circulate through fissures and cracks that develop in rock 2. Most widespread along the axis of the mid-ocean ridge system C. Produces the greatest quantity of metamorphic rock 2. Associated with mountain building D. Other metamorphic environments a. Associated with very thick accumulations of sedimentary strata b. Required depth varies from one location to another depending on the prevailing geothermal gradient 2. Cataclastic metamorphism along fault zones a. Occurs at great depth and at high temperatures b. Pre-existing minerals deform by ductile flow 3. Extremely high pressure mm caused by high speed meteorite impact b. Products are called impactiles VI. Systematic variations in the mineralogy and often the textures of rocks related to the variations in the degree of metamorphism metamorphic grade B. Index minerals and metamorphic grade 1. Changes in mineralogy from regions of low-grade metamorphism to regions of high-grade metamorphism 2. Certain minerals, called index minerals, are good indicators of the metamorphic environment in which they form a. High-grade environments often produce rocks containing the mineral sillimanite a. Most extreme environments where parent rock is partially melted b. Contain light bands of igneous, or igneous-appearing, components along with dark bands consisting of unmelted metamorphic rock VII. Metamorphism and plate tectonics A. Most metamorphism occurs in the vicinity of convergent plate boundaries 1. Compressional forces squeeze and deform the edges of the plate 2. Large-scale metamorphism also occurs along subduction zones 1. Several metamorphic environments exist 2. Important site of magma generation 3. Mountainous terrains along subduction zones are generally composed of two often distinct linear belts of metamorphic rock a. High-pressure, low-temperature nearest the trench b. High-temperature, low-pressure farther inland in the region of igneous intrusions 1. Large expanses of metamorphic rocks within the stable continental interiors a. Flat expanses of metamorphic rocks and associated igneous plutons called shields b. Most are assumed to be the remnants of much earlier periods of mountain building 3. Metamorphic mineral assemblage reflect depth of formation and amount of post orogenic erosion i.

Chapter 2 : Metamorphism | geology | calendrierdelascience.com

Ito E () High-temperature metamorphism of plutonic rocks from the Mid-Cayman Rise: a petrographic and oxygen isotopic study. PhD dissertation, Univ of Chicago Google Scholar Ito E, Clayton RN () Submarine metamorphism of gabbros from the Mid-Cayman Rise: an oxygen isotopic study.

Temperature and pressure are the primary agents that drive metamorphism. Other factors that tend to promote metamorphism include the presence of fluids mainly water , accumulated elastic strain, and small particle size. Commonly, they show evidence of having been deformed and metamorphosed at great depth in the crust. The conditions under which they were metamorphosed are those of regional metamorphism. We can make a reasonable approximation of the temperature and pressure conditions of regional metamorphism from what you have learned about the geothermal gradient and the pressure gradient. Since both T and P increase with depth, we can consider how they vary together; we know the T and P gradients. Recall from the geothermal gradient you can determine the temperature at a depth of interest. If you assume the pressure at that same depth is equal to the weight of the overlying column of rocks, using a reasonable density for the rocks, you can make a fairly good approximation of the pressure. The two lines on the graph below show the covariance of T and P in areas that have high geothermal gradients and in areas of low geothermal gradients. The two lines shown on the figure set the P-T boundary of the conditions of regional metamorphism. Where the temperature is low, the pressure is low; where the temperature is high, the pressure is high. The terms low grade, intermediate grade, and high grade metamorphism refers to these P-T conditions. At the highest grades of regional metamorphism, rocks can begin to melt in the presence of sufficient water. Rocks can also be heated by intruding magmas, and the increase in their temperature can cause them to become metamorphosed. Because magmas often rise to very shallow levels in the crust and of course often erupt , they carry their heat into low pressure environments. This heat is conducted into the rocks the magmas intrude. The graph shows the approximate conditions of contact metamorphism. Note the conditions can be high temperature and low pressure. Consequently, contact metamorphic rocks are found adjacent to plutonic rocks. The metamorphic grade is highest at the contact and lessens with increasing distance from the contact. Thin bands of contact metamorphic rocks are sometimes formed beneath lava flows. Blueschist metamorphism occurs under conditions of low temperatures and a range of pressures. It seems that conditions of low T and high P exist only in special places. The high pressures required to produce some of the characteristic mineral assemblages found in blueschists imply that the metamorphism occurs deep in the Earth where temperatures normally are also high. Recall from the introductory material you read about tectonic plate boundaries. At convergent boundaries, cold and dense plates are subducted or sink into the hotter and less dense mantle. Recall also how exceedingly slow silicate rocks conduct heat. Consequently these subducting plates can reach considerable depths where the pressures are high , long before they have had time to warm. Here rocks under go high pressure and low temperature metamorphism. As they are being deformed, a variety of textural fabrics that develope in metamorphic rocks produce the planar features we refer to as foliation. Three common types of foliation are a compositional banding that is manifested by alternating bands of different minerals, such as light color bands rich in feldspars and quartz and dark bands rich in biotite or amphiboles. Rocks possessing this type of foliation have the name gneiss. The planes of this alignment are perpendicular to the principle compressional stress during the deformation. Rocks possessing this type of foliation are referred to as schist. These are planes in which microscopic size mica grains crystallize during metamorphism. This type of foliation also forms perpendicular to the principle compressional stress. The rocks are slate. Metamorphic rocks which possess these types of foliations are those formed during regional and blueschists metamorphism. Rock names generally include the name of abundant minerals or important metamorphic minerals e. Most schist and slates are formed by the metamorphism of shales. Some likely were formally volcanic rocks There are other common metamorphic rocks that form during regional metamorphic that are either unfoliated or the foliation is weak and not as easily seen. These include quartzite - composed of recrystallized quartz grains. Most quartzites are formed by metamorphism of quartz rich sandstones. Most marbles from by the metamorphism of limestones amphibolite - contains amphiboles and plagioclase mainly; can exhibit foliation due to alignment of elongated amphibole minerals. Most formed by metamorphism of basalts I suggest that you look at some pictures of metamorpic rocks and their foliation here and here. Index minerals characterize various grades of metamorphism. Considerable experimental work has been done providing information on the range of temperatures and pressures in which certain minerals form during metamorphism. Therefore it is often possible to deduce from metamorphic rocks. The temperature, pressure, and from the foliation the orientation of stress field that existed during metamorphism.

Chapter 3 : Igneous rock - Wikipedia

Rocks collected from the axial valley wall of the Mid-Cayman Rise using the deep-sea diving vessel Alvin presented us with such an opportunity SAMPLE DESCRIPTION The rocks used in this study were collected directly from the southeastern rift valley wall of the Mid-Cayman Rise (Fig. 1) by the members of the Cayman Trough Project (BALLARD et al.

Regional metamorphism Regional metamorphism is associated with the major events of Earth dynamics , and the vast majority of metamorphic rocks are so produced. Most regionally metamorphosed rocks develop primarily in response to continent-continent collision and to collision between oceanic and continental plates. As a result, young metamorphic belts aligned roughly parallel to the present-day continental margins e. Although the processes that formed each of these mountain belts are broadly similar, in almost all such crustal events at different times and places, there is uniqueness as well as conformity to a general pattern. Metamorphic events in the Alps, the Urals , and the Himalayas all show specific differences: Rapid subduction of the cool oceanic lithosphere perturbs the thermal regime in such a way that high pressures can be obtained at relatively low temperatures, thereby generating blueschists and eclogites high-pressure facies series from ocean-floor basalts transported down the subduction zone. Continued subduction of these rocks to great depth may eventually result in either 1 rising temperatures and partial melting of subducted rocks or 2 the melting of hydrated peridotite created by fluids released from metamorphic reactions in the subduction zone that rise into the overlying mantle wedge. These melts contribute to the formation of the volcanoes that overlie subduction zones in areas such as the Andes of South America , Japan, and the Aleutian Islands. Upward migration of subduction-related magmas also contributes to the development of paired metamorphic belts, in which high-pressure, low-temperature metamorphic rocks are flanked on the continental side by a parallel belt of low-pressure, high-temperature rocks. The latter rocks are thought to reflect perturbation of the crustal thermal regime by the passage of silicate melts generated above the subducting slab. Continued intrusion of magma over a period of time would cause an increase in crustal temperatures at relatively shallow depths and produce the high-temperature rocks adjacent to the high-pressure rocks generated in the subduction zone. Data obtained from deep earthquakes in subduction zones indicate that a descending slab of oceanic lithosphere can remain intact to depths of several hundred kilometres before undergoing complete melting or fragmentation or both and being incorporated into the surrounding mantle. Most of the high-pressure rocks that have been studied from Japan, California, New Caledonia, the Alps, and Scandinavia record maximum pressures of 10â€"20 kilobars about 9,â€"19, standard atmospheres , corresponding to subduction to depths of approximately 35â€"70 km about 22â€"44 miles. A few samples have been discovered in Norway, the Alps, and China that contain the mineral coesite, a high-pressure polymorph of quartz. Experimental studies on the stability of coesite imply minimum pressures of 30 kilobars about 29, standard atmospheres for these rocks, indicating burial or subduction to depths of approximately km 62 miles. This is termed ultrahigh-pressure metamorphism UHPM. These pressures are particularly noteworthy in that they are recorded in rocks derived from sedimentary rather than basaltic protoliths. Because of the low density , and hence greater buoyancy, of sediments relative to basalts , many geologists have argued that sediment subduction must be a rather limited process; the coesite-bearing metapelites metamorphosed pelites provide important evidence that sediment subduction can and does occur under certain circumstances. The processes by which rocks that have been partially subducted are returned to the surface are not well understood. Models have been proposed to account for uplift and exposure of these high-pressure, high-density rocks; they include scraping material from the subducting plate against the overlying crustal lithosphere, upward flow of material in response to forced convection above the subducted slab, and removal of overlying thickened crust by low-angle extensional faulting. Testing these models requires considerable petrologic and structural work in areas where high-pressure rocks are exposed. Most of the high-pressure rocks that are currently displayed in metamorphic belts around the world were metamorphosed in Mesozoic or Cenozoic timeâ€”that is, from some million years ago to the presentâ€"e. The general absence of high-pressure samples in the early rock record raises a number of interesting questions concerning Earth history. Some geologists have argued that the lack of well-developed high-pressure belts formed during Precambrian and Paleozoic time 4. Specifically, they claim that greater heat production in Archean time about 4 billion to 2. The increasing abundance of subduction-related metamorphic rocks with decreasing age in the rock record would thus reflect the gradual onset of plate tectonics as operative today. Others argue that the rock record is biased because of preferential erosion or thermal overprinting development of a new mineralogy that may obliterate the original one of old blueschists and eclogites. Early exposure at the surface also increases the chances for removal by erosion , however, resulting in a low probability for preserving blueschists greater than million to million years old. Geologists favouring generation of blueschists throughout Earth history but only selective preservation of these rocks also point to crustal rocks more than 2. These medium-pressure facies series rocks imply that crustal thicknesses in early Earth were similar to those of the present day and thus that modern plate-tectonic processes may have operated from the early Precambrian to the present. This debate, though unresolved, emphasizes the substantial knowledge of the thermal structure of Earth and plate-tectonic processes that can be obtained from the study of metamorphic rocks. Collisions of this type have a long and complex history that may include initial formation of a paired metamorphic belt followed by extreme crustal thickening in response to the actual collision of the continents. The overthickened crust produced by the collision event will be gravitationally unstable and will undergo subsequent rapid erosion and possibly extensional faulting in order to return to a normal crustal thickness. Rocks metamorphosed in the early stages of collision may belong to a high-pressure facies series, reflecting the final stages of subduction of oceanic lithosphere, whereas the younger facies more typically belong to medium-pressure facies series. Metamorphic rocks exposed in former collision zones may thus have followed a variety of pressure-temperature-time paths, but paths showing rapid burial followed by heating and subsequent unroofing at moderate to high temperatures have been reported from many mountain belts around the world. Owing to the strong directed forces operative during collision, deformation typically accompanies metamorphism; rocks metamorphosed in response to continent-continent collision generally have fabrics showing a strong preferred orientation of mineral grains, folds on a variety of scales, and pre-, syn-, and postkinematic porphyroblasts. Examples of metamorphic belts produced in response to this type of collision include the Paleozoic Appalachian and Caledonides belts and the Mesozoic-Cenozoic Alpine and Himalayan belts. Regionally metamorphosed rocks are also exposed in areas where the crust has been thinned by extensional faulting, such as the Basin and Range Province of the western United States. In this type of occurrence, areas of medium- and low-pressure facies series rocks that measure a few tens of kilometres in diameter are juxtaposed against unmetamorphosed sediments or very low-grade metamorphic rocks along low-angle extensional faults. Metamorphic grades refer to the degree and intensity of the metamorphism: Such areas are generally referred to as metamorphic core complexes. Metamorphism in these complexes may or may not be related to the extensional event. In some instances, metamorphic rocks produced during much earlier events are simply unroofed and exposed by the faulting but show little or no recrystallization related to extension. In other cases, prolonged extension has resulted in an increased crustal geotherm, and relatively high-temperature metamorphism and magmatism is thus directly related to the extensional event. Immediately adjacent to the faults , the rocks may also be affected by dynamic metamorphism. The facies associated with regional metamorphism include, at low grade, the zeolite and prehnite -pumpellyite facies. In areas belonging to high-pressure facies series, the rocks are predominantly in the blueschist and eclogite facies. Medium- and low-pressure facies series are typified by rocks belonging to the greenschist, amphibolite , and granulite facies. Zeolite facies In the zeolite facies, sediments and volcanic debris show the first major response to burial. Reactions are often not complete, and typical metamorphic fabrics may be poorly developed or not developed at all. This is the facies of burial metamorphism. The zeolite facies was first described from southern New Zealand, but similar rocks have now been described from many younger mountain regions of Earth, particularly around the Pacific margin and the European Alps. Typical mineral assemblages include heulandite , analcite, quartz with complex clay minerals montmorillonite , micaceous phases such as chlorite and celadonite, and the potassium feldspar adularia. At higher grades of metamorphism, the zeolite laumonite and the feldspar albite dominate the mineral assemblage. In New Zealand these are developed in a rock column that is about 15 km 9. Calcareous rocks impure limestones show very little response to this grade of metamorphism. Prehnite-pumpellyite facies Along with the zeolite facies , the prehnite-pumpellyite facies received little attention until about The first rocks of the facies were described in New Zealand and Celebes. The facies is transitional, bridging the path to the blueschist facies or the greenschist facies. It is particularly well developed in graywacke-type sediments. The two minerals prehnite and pumpellyite replace the zeolite minerals of the zeolite facies and are themselves replaced by epidote minerals in the greenschist facies and by lawsonite and pyroxenes in the blueschist facies. Typical minerals in this facies are quartz, albite, prehnite, pumpellyite, chlorite, stilpnomelane, muscovite , and actinolite. Almost all the minerals are hydrated, and, except for chlorite, they bear little resemblance to the minerals of sediments. This facies has been most described from younger mountain ranges of the Pacific margin. Blueschist facies Rocks of the blueschist facies represent deep metamorphism under conditions of a low thermal gradient. The characteristic locale for this type of metamorphism appears to be along a continental margin being underthrust by an oceanic plate. Regions in which blueschists are found are also regions of great seismic and volcanic activity, such as the Pacific margin. The best described examples of this class of metamorphism come from California, Japan, New Caledonia, Celebes, the Alps, and the Mediterranean region. At present there are no confirmed examples of glaucophane schists predating the Paleozoic Era. Because of the presence of the blue amphibole glaucophane and minerals such as garnet and jadeite, these schists are among the most attractive of metamorphic rocks. Characteristic minerals of the facies include quartz, glaucophane, lawsonite, jadeite , omphacite, garnet , albite , chlorite , muscovite , paragonite , epidote , and kyanite. In calcareous rocks, calcite may be replaced by the high-pressure polymorph aragonite. In general, the facies is characterized by many high-density minerals reflecting a high pressure of formation. Eclogite facies The eclogite facies was initially recognized in rocks only of basaltic composition , which are transformed at the pressure-temperature conditions of the eclogite facies into spectacular red and green rocks composed of the anhydrous mineral assemblage garnet plus omphacite. The garnet is rich in the high-pressure species pyrope , and the omphacite is rich in the high-pressure pyroxene jadeite. Small amounts of minerals such as kyanite, zoisite , and hornblende may be present. The rocks are of high density and frequently show little or no schistosity. It is now known that protoliths other than basalt also can be metamorphosed to pressures and temperatures characteristic of the eclogite facies, and a wide variety of mineral assemblages can be stable at these conditions, including several hydrous mineral phases. Minerals that have been observed in metapelites include magnesium -rich chloritoid and staurolite , kyanite, garnet, phengite a muscovite mica with high magnesium and silicon and low aluminum content , chlorite, and talc. Experimental work shows that pelitic rocks composed primarily of talc and kyanite, which are referred to as whiteschists, can be stable from pressures of approximately 6 kilobars about 5, standard atmospheres up to greater than 30 kilobars about 29, standard atmospheres. Minerals observed in eclogite-facies calcareous rocks include magnesite , dolomite , zoisite or epidote, and omphacite. Because of the high density and composition, it was proposed long ago that part of the upper mantle might be made of eclogite. Such a view is supported by eclogitic intrusions in volcanic rocks and by eclogitic inclusions in diamond-bearing kimberlite , which must come from the upper mantle. Some workers also think that eclogites found in metamorphic terrains in Norway , California , U. Early experimental work on eclogites of basaltic bulk composition suggested that eclogites could generally be stable only if water pressure was much lower than the lithostatic pressure the stress exerted on a body of rock by surrounding rock , and the facies was thus thought to represent dry high-pressure metamorphism of basaltic protoliths. Subsequent work on the more diverse protolith compositions revealed, however, that a wide range of water pressures is possible in the eclogite facies and that fluid compositions in equilibrium with the eclogite minerals also probably vary greatly. Indeed, fluid inclusions tiny bubbles of fluid trapped within mineral grains in eclogite samples provide evidence of fluids containing nitrogen , salts , and carbon dioxide in addition to water. Eclogite metamorphism is therefore not confined to dry environments but results instead from metamorphism of a variety of rock types at pressures above about 10 kilobars, corresponding to burial to approximately 35 km The temperatures of the eclogite facies overlap those of the greenschist , amphibolite , and granulite facies , but the higher pressures result in distinctly different mineral assemblages characterized by high-density mineral phases. Greenschist facies The greenschist facies was once considered the first major facies of metamorphism proper. The name comes from the abundance of the green mineral chlorite in such rocks. Because chlorite and muscovite are ubiquitous and because both exhibit a platy crystal habit, these rocks normally show a highly developed foliation and often exhibit strong metamorphic differentiation. They have been described from practically every metamorphic terrain on Earth , from earliest Precambrian to the young mountain regions. The dominant minerals of greenschists formed from silicate -rich sediments include quartz , albite, muscovite, chlorite, epidote, calcite , actinolite , magnetite , biotite , and paragonite. Minerals less common include the manganese -rich garnet spessartine , stilpnomelane, kyanite , rutile , sphene titanite , pyrophyllite , and chloritoid. Calcareous rocks are dominated by calcite, dolomite, and quartz; the major carbonate minerals are thermally stable. It is only when large quantities of water flush away carbon dioxide or keep its partial pressure low that carbonate-silicate reactions take place and liberate carbon dioxide. The typical minerals of this facies have lower water contents than the zeolite facies minerals do. Amphibolite facies The amphibolite facies is the common high-grade facies of regional metamorphism, and, like the greenschist facies, such rocks are present in all ages from all over the world.

Chapter 4 : Metamorphism In Space And Time Quiz - ProProfs Quiz

Ito E () High-temperature metamorphism of plutonic rocks from the Mid-Cayman Rise: a petrographic and oxygen isotopic study. PhD dissertation, University of Chicago Google Scholar Ito E, Anderson AT Jr () Submarine metamorphism of gabbro from the Mid-Cayman rise: petrographic and mineralogic constrainst on hydrothermal processes at slow.

The Rangeley has been described as an olistostrome Eusden et al. As the state map was being compiled, Thompson , discovered structural complications on the BHA, arising from the recognition of distinct stratigraphic units based on fossil occurrences in rocks that had previously been mapped as belonging to one formation. This lead to a second round of mapping in the region, still referencing the Littleton section, that culminated in the oft-cited paper by Thompson and others, establishing the current paradigm outlined above. Billings and others , , had earlier wrestled with this problem in the Mount Washington-Gorham area further north, and in revisiting this area Hatch and others ; Duke et al. A key component of this interpretation is the recognition of a change in depositional environments, from a shelf-type on the BHA to a deep closed basin in the CMT. A third generation of mapping was undertaken in western NH to determine the relationship between the stratigraphy of rocks on the BHA and that to the east in central NH Chamberlain et al. While the rocks themselves have remained essentially unchanged for several hundred million years, their exposures too often too few and far between and our interpretations of them seem to change continuously. The release of a new NH state geologic map is imminent Lyons et al. At that time, the details of age relationships, the sources of these magmas, and their modes of emplacement were uncertain. Since then, the application of radiometric dating techniques, petrologic and isotopic studies, geophysical and structural investigations, and thermal modelling have vastly improved our understanding of the Oliverian and NHPS rocks. These rocks have an internal gneissic foliation paralleling their contacts with wall rocks, giving rise to their sometimes asymmetric domal structures. Structures within the mantling strata, including Silurian and Devonian rocks substantially younger than the core gneisses, also exhibit this doming. In addition, metamorphic isograds in these strata commonly wrap around the domes, with the grade of metamorphism increases toward the center of the dome. It is thought that the domes might have been created by diapiric rise Thompson et al. Such a model has been demonstrated by scaled gravity tectonic experiments Ramberg, Lyons and others used gravity measurements to confirm the geometry of these domes, and their mushroom- shaped models support reactivated diapiric rise of the core rocks. The cores of the domes may also represent relict volcanic islands of an oceanic island arc Hitchcock, , c. One school of thought suggests that the docking of the Bronson Hill island arc with the Laurentian continent was responsible for the Taconic orogeny. Of these, the Mount Clough pluton and the Cardigan pluton are the most voluminous. Both of these plutons are heterogeneous granitoids, ranging from granite sensu stricto to quartz diorite but being predominately granodiorite. Characteristic of the KQM are abundant potassium feldspar megacrysts in a course groundmass of quartz, plagioclase, biotite, muscovite and garnet. In some places, garnet becomes the dominant mineral suggesting zones of restite entrained within the magma. The Bethlehem Gneiss is a more homogeneous micaceous granodiorite distinguished from the KQM by a prominent gneissic foliation and the lack of potassium feldspar megacrysts and restites. Lathrop and others , made detailed Sr, Nd and O isotopic studies of the Mount Clough and Cardigan plutons to address questions about the nature of origin and source for these rocks. Their results show that, while isotopically heterogeneous and complex, the Bethlehem Gneiss and KQM magmas formed from anatectic melting of the adjacent metasedimentary rocks found in the BHA and the CMT, with very little if any contribution from the mantle. However, the rocks of the BHA are not so enriched, and so would have required an external heat source or deeper burial for melting. Geophysical investigations, combined with geologic structural constraints, indicate that these plutons are floored by metasedimentary rocks and were probably emplaced as large sill-like bodies, not much thicker than about meters Nielson et al. It is thought that several of these plutons may have at one time been connected, covering the entire area; the Bellows Falls Pluton perhaps being an outlier of the Mount Clough Pluton, for example. It should further be noted that the Bethlehem Gneiss and the KQM cannot be distinguished from one another on the basis of Nd, Sr, or O isotope compositions Lathrop et al. Differences in texture could be related to the degree to which the plutons were involved in nappe-stage deformation, the Mount Clough pluton of Bethlehem Gneiss being the further west on the eastern flanks of the BHA, while the Cardigan pluton is within the CMT. Allen proposed , that the upper-most Fall Mountain nappe may have been aided in its transport to the west by the intrusion of Bethlehem Gneiss as a sheet along its sole, such that the Fall Mountain outlier and the Bellows Falls pluton are a package. Structure and Metamorphism Thompson and others mapped a series of several west-vergent isoclinal fold nappes lying on and lapping over the BHA. These were recognized on the basis of repeats and inversions of the stratigraphy as well as structural features. Further to the south, thrust faulting was recognized as an intermediate stage between emplacement of the fold nappes and subsequent doming Thompson et al. Clearly, not all of the nappes are strictly fold nappes, the upper-most Fall Mountain nappe probably being more of a thrust structure Allen, , , Chamberlain et al. On the eastern flanks of the CMT, to the east of the Central NH Anticlinorium, a somewhat similar set of early nappes are recognized, there being east-vergent Eusden et al. The Central NH Anticlinorium is interpreted as a "dorsal zone" or "pop-up" structure forming the core of the Acadian orogeny Eusden et al. The succession of nappes emplaced over the BHA explained the inversion of metamorphic isograds observed in the region Chapman, Each nappe, rooted to the east of the BHA in the CMT, brought deeper, hotter rocks westward with it, over colder previous nappes and autochthonous rocks. Thus rocks of high metamorphic grade were correlated to high tectonic level, in this case later nappes Thompson et al. Spear and others , ; Kohn et al. Indeed, they have gone on to postulate the existence of additional nappes or thrust sheets , that are not exposed anywhere, on the basis of P-T-t histories. Chamberlain has explained these as the result of metamorphism enhanced by sequential episodes of intersecting folds. Conclusion The geology seen here in west-central NH appears to be characteristic of many orogenic belts. Thompson and others drew analogies between their interpretation of nappes and gneiss domes with similar structures observed in the western Alps, as further developed by Thompson and others , Acknowledgements I would like to express my sincere appreciation to C. Page Chamberlain, James B. Lyons for first showing me these outcrops, and introducing me to and involving me in the study of the geology of my home stomping grounds. Any errors or omissions are mine alone. Road Log We will depart at 8: Please carpool, bring a lunch, and have a full tank of gas -- enough for at least miles of driving. Leave hazard indicators flashing. Border Gneiss of the Keene Dome 10 minutes The Oliverian rocks of the Keene Dome are non-peraluminous granodiorite to quartz monzonite, here strongly laminated in the border region of the dome, adjacent to Surry Mountain -- a septum of metasediments between the Keene and Alstead domes, in a vertical syncline that folds the axial plane of the nappes. Within the border gneiss, one finds thin mafic layers and quartz "eyes. Surry Mountain Septum 10 minutes Exposed here are some of the metavolcanic and metasedimentary rocks of the Surry Mountain septum see stop 1 above. We may find gedrite- cordierite assemblages in a "garbenschiefer" texture better exposed up on Surry Mountain ; the rock is also reported to contain Na-micas with talc intergrowths J. Return to the vehicles and continue east. Take care in crossing the highway. Spear mapped these rocks as the upper plate of the Chesham Pond nappe, and interprets the P-T-t path as cooling following thrust emplacement and backsliding. Return to the vehicles and continue north on The rocks are highly foliated. Continue west on Continue straight through on west Continue through on west Take care in crossing the highway and scrambling down to the outcrops in the river. Gray schists of the Rangeley Formation from the CMT, containing characteristic calc-silicate and amphibolite "pods," is here in contact with the Bethlehem Gneiss of the Bellows Falls pluton. Note the sillimanite pseudomorphs after andalusite "turkey tracks" in the schist, and garnets in the Bethlehem Gneiss associated with assimilated blocks of schist. The CMT rocks on Fall Mountain were clearly of higher metamorphic grade than the BHA rocks surrounding and underneath the Bellows Falls pluton, which implies significant horizontal transport from the root zone in Marlow. Much of this transport and shortening may have been taken up within the Bellows Falls pluton Allen, , ; Spear, The metamorphic evolution of Fall Mountain shows cooling following emplacement of hot rocks over cold Allen, ; Spear develops a more complex scenario. Return to the vehicles and continue north on Rt. The rocks here are a staurolite schist and quartzite showing spectacular graded bedding grade reversed due to metamorphism characteristic of a turbidite deposit. The rocks are isoclinally folded and otherwise deformed, with inverted topping directions and several hinges apparent. Much of the deformation may well have occurred during deposition, when these rocks were still soft sediment. These rocks are part of the Skitchewaug nappe, structurally below the Bellows Falls pluton and the Fall Mountain nappe. P-T paths from other outcrops in this section show heating with loading Spear, , consistent with the emplacement of the hot Fall Mountain rocks over these colder rocks. After getting your photographs, return to the vehicles and continue along the dirt road. Similar fossils have been found in several other locations within the Clough Quartzite throughout the region, such that it is a good Silurian marker and very useful in deciphering the stratigraphy and structure of the BHA. Continue north on 5. This may well be our Lunch Stop. Take care in crossing the highway to roadcuts at the intersection. Blue quartz eyes in pyroclastic volcanics 15 minutes The blue quartz eyes, from the exsolution of very fine rutile crystals within the quartz, are indicative of very high temperatures, but these rocks have only been metamorphosed to biotite zone low grade. This rock represents a high-temperature volcanic ignimbrite, with lenticles of pumice, lapilli, etc The coarse pyroclastic sequence is best visible on a water polished surface cross back to the riverside park. A slaty cleavage has been superposed, creating a lineation in the rock. Look down-dip to see these features. Continue through all the stoplights along this strip. Spaulding Quartz Diorite and pegmatite autoliths 15 minutes: The Spaulding, dated at million years, somewhat foliated, cross-cuts the KQM and the Bethlehem Gneiss, thus a late tectonic intrusive. Here it is cut by pink pegmatites with perthitic feldspar. The pegmatite and the Spaulding are magmatically related, and here you can see "autoliths" of the pegmatite within the Spaulding and vice-versa. At the north end of the outcrop are true xenoliths as opposed to autoliths of the country rock, including the KQM. In some places the KQM has become disaggregated, with incorporation of feldspar xenocrysts into the Spaulding. This represents an igneous breccia, with flow foliation, resulting from explosion venting of fluidized magma. Return to the vehicles and enter Rt. The ridge extending south-southwest from Mount Sunapee to Lempster Mountain, and north from Sunapee to Mount Cardigan, represents a septum of metasediments interdigitated with the Huntley Mountain Spur caught between the Cardigan pluton to the east and the Mount Clough pluton to the west. Mapped by Dean based on the BHA stratigraphy, a new look at these rocks with insights from the CMT and other areas, may help tie together the stratigraphy and structure of southwestern NH with that to the north and west, as well as furthering our understanding of the relationships between the Cardigan and Mount Clough plutons. Leave hazard indicators flashing, and take care in crossing the highway. Across the road is an interesting outcrop of the KQM.

Chapter 5 : Metamorphism: Kinds, Effects and Grades | Rocks | Geology

The coarse-grained, submersible-collected rocks from the Mid-Cayman Rise in our study span a vertical section of about m and range from amphibolite to gabbro.

In this article we will discuss about: Meaning of Metamorphism 2. Factors of Metamorphism 3. Kinds of Metamorphism 4. Effects of Metamorphism 6. Metamorphic Grades, Zones and Facies. Any pre-existing type of rock forming a part of the crust may or may not undergo any physical, chemical or structural change for any time after its formation. This depends upon the environment in which the rock exists. There will be, obviously, no change in the physical make up or the chemical constitution of the rock if it has adjusted itself completely to the surrounding environment. This theoretical state of no change may be explained by saying that the rock is in equilibrium with the physical and chemical environment which surrounds it. But once there is a significant and effective change in one or more of these surrounding conditions, the equilibrium is disturbed and the rock is unable to exist in its original form- it has to undergo some changes to establish the equilibrium once again. The surrounding conditions that play important role in this regard are temperature, pressure and chemically active fluids. When there is a change in any one or more of these parameters around the rock there must take place a corresponding change in the nature of the rock also. What kind of change will take place in the rock? This will depend on the nature of rock under question and the extent of change in the temperature-pressure-chemical environment set of conditions. The changed rock is called the metamorphic rock and it will be stable under the new set of conditions till there is a further change in those conditions. METAMORHISM is the term used to express the process responsible for all the changes that take place in an original rock under the influence of changes in the surrounding conditions of temperature, pressure and chemically active fluids. Metamorphic changes in the rocks are primarily the result of three main factors that are also sometimes called as agents of metamorphism: These agents may act individually or collectively. The metamorphic changes are most pronounced when these factors operate collectively and in a big way. However, when the temperature around these rocks changes due to one reason or the other, the mineral composition of the rocks undergoes some changes in order to adjust to the new temperature conditions. Two common sources of heat for such a metamorphism to take place are the internal heat increase in temperature with depth: The internal heat becomes operative when rocks formed at surface e. Similarly, when a magmatic intrusion like a sill or a dyke invades the country rock from below, the host rocks around the margins of intrusion suffer sudden and enormous changes in their temperature. They are also metamorphosed in order to be stable under the new conditions. Many metamorphic changes are induced solely due to the pressure factor whereas in great majority of cases pressure is the dominant factor and is assisted considerably by the heat factor. Any given rock at some depth below the surface is subject to pressure from two sources- first, load of the overlying burden and second, crustal movements during the convergence of the tectonic plates. The first type of pressure acts generally in a vertical direction and the process of change in the structure of the rock are often referred as load metamorphism. The pressure from orogenic activity is generally lateral or horizontal and is commonly termed as directed pressure. Rocks situated near the plate boundaries or within the geosynclinal belts are especially prone to directed pressure and often show severest degree of metamorphic changes. Presence or absence of chemically active fluids within the body of the rocks the pore fluids or around them plays very important role in the process of all types of metamorphism. With the rise in temperature, the pore fluids undergo expansion and become very active in disturbing or even breaking the original crystal boundaries of the involved minerals. New minerals are created that are stable in the changed conditions. This process is called recrystallisation that takes place essentially in a solid state. Sometimes fluids present around the rocks also come in contact with them at elevated temperatures and react with the minerals within the rocks producing many changes in their composition and structure. This type of change is termed metasomatism. Among such chemically active pore fluids and external fluids may be mentioned water, carbon dioxide, hydrofluoric acid, bromine and fluorine. Water in the form of steam is considered the single most important agent. The water may be present in the minerals as water of crystallisation or simply as pore fluid or it may be supplied externally by magmatic bodies. Three major kinds of metamorphism differentiated on the basis of factor most dominant in causing it are: It is a general term including a variety of metamorphic processes in which the heat factor has played an important role. The pressure and chemically active fluids, though operating are attributed assisting roles. Contact Metamorphism is a common type of thermal metamorphism observed in rocks existing close to the magmatic intrusions, injections and lava flows. In this case, the heat from magmatic source travels through the body of the surrounding rocks that undergo structural and mineralogical changes depending upon their original composition and intensity of the heating effects. Other things being the same, the effect is most intense in the immediate neighbourhood of the magmatic source and decreases with distance from the contact points. Pyrometamorphism is another type of thermal metamorphism in which case a part of country rock may actually get entrapped within a magmatic body. The effects result due to intense localized heating short of melting. It is illustrated by changes in a block of sedimentary rock that has incidentally fallen in a body of flowing lava. The block may be so much heated up that its original minerals are forced to recrystallise and rearrange themselves in accordance with the conditions imposed by the acute rise in temperature. Plutonic Metamorphism is a process of metamorphism that takes place due to equally important role of imposed loads due to burial at great depths and very high temperatures that become natural at those great depths. Such changes take place in rocks that are pushed down during crustal movements to positions where high temperature and high pressure become almost a permanent feature. In all types of thermal metamorphism the change is generally in the direction of mineralogical reconstitution. These processes may induce changes varying from simple baking effect optalic metamorphism to complete or nearly complete recrystallisation of almost all of the original minerals. It is also called clastic metamorphism, mechanical metamorphism or dislocation metamorphism and is brought about by conditions in which pressure factor plays a dominant role. Sometimes the pressure is of the type of hydrostatic type such as load of the overlying rocks. The process is then called load metamorphism. In the dynamic metamorphism, there is no or very little formation of new minerals compare with the thermal metamorphism. These are the original textures and structures of the rocks that are partially or totally obliterated. New textures and structures are imposed on the effected rocks. This involves development of large-scale changes in the structural and chemical constitution of the pre-existing rocks under the combined action of pressure, temperature and fluids. Such conditions were available during the mountain building activity repeatedly in the history of the Earth. The latest plate-tectonics theories also postulate convincingly development of conditions leading to the large-scale regional metamorphic effects at the margins of converging tectonic plates. Metamorphic rocks formed through regional metamorphism occur in the form of extensive mountain belts and also as the core portions of many old eroded mountain systems throughout the world. They bear evidence of formation of new minerals as well as imposition of new textures and structures on an extensive scale. The chemically active fluids may be provided: This is sometimes referred as mineral metasomatism. The net result would be a definite change in the bulk chemical composition of the rock as a whole. This is, therefore, sometimes referred as rock metasomatism. The process of metasomatism is sometimes further distinguished into: Hydrothermal â€” when the fluids are in the form of solutions; ii. Pneumatolytic â€” when the fluids are in the form of gases or vapours; iii. Additive â€” when the net result of the process is addition of a new constituent; and iv. Expulsive â€” when some component gets removed from the original composition of the rock. A common fact observed in the case of metasomatism is that the total volume of the rock remains by and large unchanged after the process is completed. Further, the changes can take place over a wide range of temperature and pressure and like other metamorphic processes are completed essentially in solid state. Metasomatism is quite common in silicate and carbonate rocks. A variety of changes may be caused in pre-existing rocks subjected to metamorphic processes. This depends primarily on following two major factors: Generally speaking, the metamorphic process may result in one or more of the following main categories of effects on the involved rocks:

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Chapter 6 : Nappes, Gneiss Domes and Plutonic Sheets of West-Central New Hampshire

Note the conditions can be high temperature and low pressure. Consequently, contact metamorphic rocks are found adjacent to plutonic rocks. The metamorphic grade is highest at the contact and lessens with increasing distance from the contact.

For a more detailed classification see QAPF diagram. Example of classification Granite is an igneous intrusive rock crystallized at depth , with felsic composition rich in silica and predominately quartz plus potassium-rich feldspar plus sodium-rich plagioclase and phaneritic, subeuhedral texture minerals are visible to the unaided eye and commonly some of them retain original crystallographic shapes. The continental crust is composed primarily of sedimentary rocks resting on a crystalline basement formed of a great variety of metamorphic and igneous rocks, including granulite and granite. Oceanic crust is composed primarily of basalt and gabbro. Both continental and oceanic crust rest on peridotite of the mantle. Rocks may melt in response to a decrease in pressure, to a change in composition such as an addition of water , to an increase in temperature, or to a combination of these processes. Other mechanisms, such as melting from a meteorite impact , are less important today, but impacts during the accretion of the Earth led to extensive melting, and the outer several hundred kilometers of our early Earth was probably an ocean of magma. Impacts of large meteorites in the last few hundred million years have been proposed as one mechanism responsible for the extensive basalt magmatism of several large igneous provinces. Decompression Decompression melting occurs because of a decrease in pressure. If such rock rises during the convection of solid mantle, it will cool slightly as it expands in an adiabatic process , but the cooling is only about 0. If the rock rises far enough, it will begin to melt. Melt droplets can coalesce into larger volumes and be intruded upwards. This process of melting from the upward movement of solid mantle is critical in the evolution of the Earth. Decompression melting creates the ocean crust at mid-ocean ridges. It also causes volcanism in intraplate regions, such as Europe, Africa and the Pacific sea floor. There, it is variously attributed either to the rise of mantle plumes the "Plume hypothesis" or to intraplate extension the "Plate hypothesis". Water lowers the solidus temperature of rocks at a given pressure. Hydrous magmas composed of basalt and andesite are produced directly and indirectly as results of dehydration during the subduction process. Such magmas, and those derived from them, build up island arcs such as those in the Pacific Ring of Fire. These magmas form rocks of the calc-alkaline series, an important part of the continental crust. The addition of carbon dioxide is relatively a much less important cause of magma formation than the addition of water, but genesis of some silica-undersaturated magmas has been attributed to the dominance of carbon dioxide over water in their mantle source regions. At greater depths, carbon dioxide can have more effect: Temperature increase Increase in temperature is the most typical mechanism for formation of magma within continental crust. Such temperature increases can occur because of the upward intrusion of magma from the mantle. Temperatures can also exceed the solidus of a crustal rock in continental crust thickened by compression at a plate boundary. The plate boundary between the Indian and Asian continental masses provides a well-studied example, as the Tibetan Plateau just north of the boundary has crust about 80 kilometers thick, roughly twice the thickness of normal continental crust. Studies of electrical resistivity deduced from magnetotelluric data have detected a layer that appears to contain silicate melt and that stretches for at least 1, kilometers within the middle crust along the southern margin of the Tibetan Plateau. Temperature increases also may contribute to the melting of lithosphere dragged down in a subduction zone. Magma evolution Schematic diagrams showing the principles behind fractional crystallisation in a magma. While cooling, the magma evolves in composition because different minerals crystallize from the melt. At the bottom of the magma reservoir, a cumulate rock forms. Igneous differentiation Most magmas only entirely melt for small parts of their histories. More typically, they are mixes of melt and crystals, and sometimes also of gas bubbles. Melt, crystals, and bubbles usually have different densities, and so they can separate as magmas evolve. As magma cools, minerals typically crystallize from the melt at different temperatures fractional crystallization. As minerals crystallize, the composition of the residual melt typically changes. If crystals separate from the melt, then the residual melt will differ in composition from the parent magma. For instance, a magma of gabbroic composition can produce a residual melt of granitic composition if early formed crystals are separated from the magma. Incompatible elements are concentrated in the last residues of magma during fractional crystallization and in the first melts produced during partial melting: Magma composition can be determined by processes other than partial melting and fractional crystallization. For instance, magmas commonly interact with rocks they intrude, both by melting those rocks and by reacting with them. Magmas of different compositions can mix with one another. In rare cases, melts can separate into two immiscible melts of contrasting compositions. There are relatively few minerals that are important in the formation of common igneous rocks, because the magma from which the minerals crystallize is rich in only certain elements: These are the elements that combine to form the silicate minerals , which account for over ninety percent of all igneous rocks. The chemistry of igneous rocks is expressed differently for major and minor elements and for trace elements. Contents of major and minor elements are conventionally expressed as weight percent oxides e. Abundances of trace elements are conventionally expressed as parts per million by weight e. The term "trace element" is typically used for elements present in most rocks at abundances less than ppm or so, but some trace elements may be present in some rocks at abundances exceeding 1, ppm. The diversity of rock compositions has been defined by a huge mass of analytical dataâ€”over , rock analyses can be accessed on the web through a site sponsored by the U. Etymology The word " igneous " is derived from the Latin ignis, meaning "of fire". Volcanic rocks are named after Vulcan , the Roman name for the god of fire. Intrusive rocks are also called "plutonic" rocks, named after Pluto , the Roman god of the underworld. Geological Society of America Bulletin. Understanding the Earth 2nd ed. Medard, The influence of H_2O on mantle wedge melting. Earth and Planetary Science Letters, v. Hirschmann Effect of variable carbonate concentration on the solidus of mantle peridotite. Le Maitre editor Igneous Rocks: