7. Give short answers to the following questions;

a) What is the definition of metamorphism and what grain-scale processes are involved?
b) Give a short description of a schist, a gneiss and a migmatite.
c) What is the pressure at the base of the crust at a depth of 30 km. Note that crustal density is about 2700 kg/m^3, g =9.8 m/s^2, SI units of pressure are Pa and 1 kilobar (kb) = 100 MPa.
d) How can you distinguish metamorphic rocks from igneous and sedimentary rocks in the field?
e) What is the difference between dynamic metamorphism and regional orogenic metamorphism?

a) (2 points) Sum of all changes (minerals, grainsize and grain shape) that occur when the PT environmental conditions are changed. Processes are mineral transformations, reactions, recrystallization and deformation.

b) (2 points) Schist, metamorphic rock with continuous foliation; gneiss.partly foliated structure; migmatite mixed rock with igneous layers (produced by melting) and foliated layers of residue from melting.

c) (2 point) P=g x density x depth 9.8 x 2700x 103 x 30x 103=793.8 MPa =7.9 kb about 8kb

d) (2 points) Metamorphic rocks have foliations and porphyroblasts, clasts. Sedmentary rocks have bedding, sedimentary structures, clastic grains; igneoud rocks have interlocking grains and usually no banding or foliation.

e) (2 points)Dynamic..recrystallization reaction and deformation in local high strain zone. Regional..reaction and deformation and heating in mountain range.

1 - 1
2 - 1.5
3 - 2

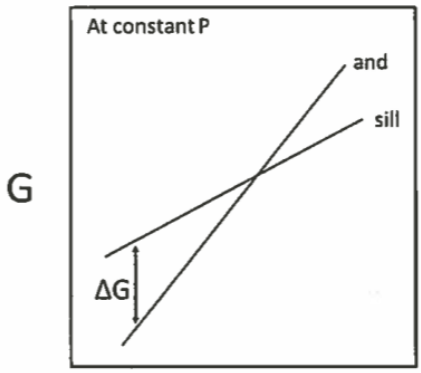
8. Some rocks in a metamorphic belt contain the following minerals: jadeite = $NaAlSi_2O_6$, quartz = SiO_2 , Andalusite Al_2SiO_5, Silliminite Al_2SiO_5, and albite $NaAlSi_3O_8$

a) How many chemical components are needed to describe these rocks and minerals?

b) What chemical reactions and polymorphic reactions can occur in this system?

c) Define the phase rule and use this rule to determine how many minerals will be present in this system in a divariant mineral assemblage and an invariant assemblage in this chemical system.

d) The diagram shows a plot of the Gibbs free energy for sillimanite and andalusite, with increasing temperature, at constant pressure. Which mineral will be stable at high temperatures?



e) What thermodynamic parameter controls the slope of the Gibbs free energy versus temperature plot in the figure above.

0.5 albite → jad

a) *(2 points) 3 components SiO, AlO and NaO*

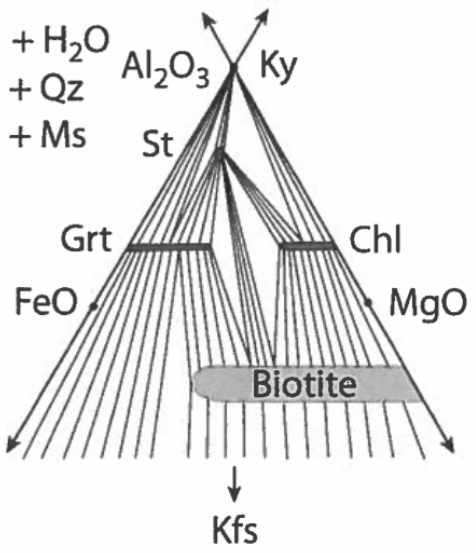
b) *(2 points) Albite = quartz + jadeite, quartz to coesite and andalusite-kyanite-sillimanite*

c) *(2 points) F (degrees of freedom)= (chemical components+2) – phase number. If C=3 then divariant is F=2 so 3 phases. Invariant F=0, so 5 phases.*

d) *(2 points) The phase with lowest gibbs free energy will be stable so sillimanite.*

e) *(2 points) Entropy is the slope dG/dT*

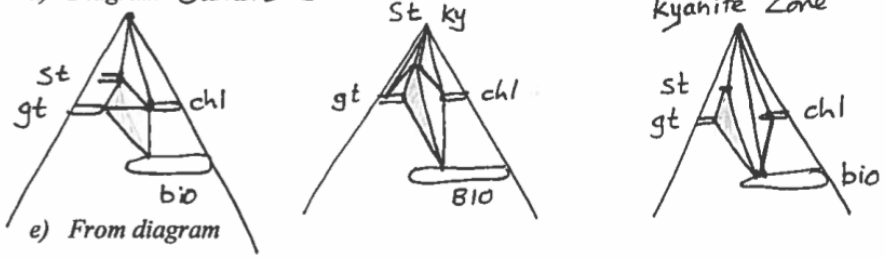
9. The figure below shows an AFM diagram for the staurolite metamorphic zone from NE Scotland. This zone occurs in a sequence of garnet zone, staurolite zone, kyanite zone and sillimanite zone.



(2 points per section) Staurolite zone

a) Why are the minerals like biotite plotted as a band of compositions?
b) Why does garnet (G) plot on the Fe rich side of the diagram and chlorite (Chl) on the Mg-rich side of the diagram?
c) Make a list of the all of the mineral assemblages containing staurolite (St) that can occur in this zone.
d) Draw AFM diagrams for the garnet zone and the kyanite zone. The reactions at each isograd are: at the strauolite "in" isograd, staurolite + biotite = garnet + chlorite + water; and at the kyanite "in"isograd, staurolite + chlorite = kyanite + biotite + water.
e) If a rock has a mineral assemblage of staurolite, garnet, biotite in the staurolite zone, what will be the mineral assemblage in the garnet and kyanite metamorphic zones?

a) Biotite is a solida solution with variable Fe/Mg ratio.
b) Fe fits better into garnet structure and Mg better into chl structure.
c) 3 phases : St-chl-bio, st-ky-chl;st-gt-bio; st-gt-ky.2 phases st-gt, st-ky. St-bio, st-chl.
d) Diagram Garnet zone



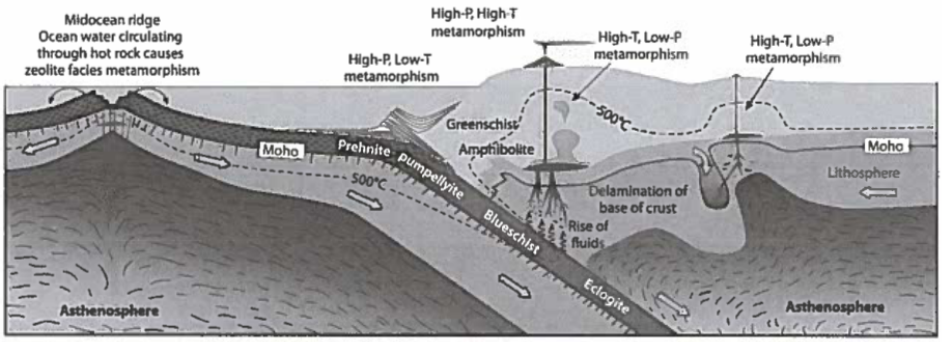
e) From diagram

St Gt chl ← St Gt Bio → St Gt Bio

or

Gt chl Bio

10. The figure below shows the pressure and temperature produced in different plate tectonic environments.



a) Draw a sketch PT diagram showing: the stability fields of the Al_2SiO_5 polymorph minerals, the amphibole glaucophane, the pyroxene omphacite and the three main types of metamorphic field gradient.

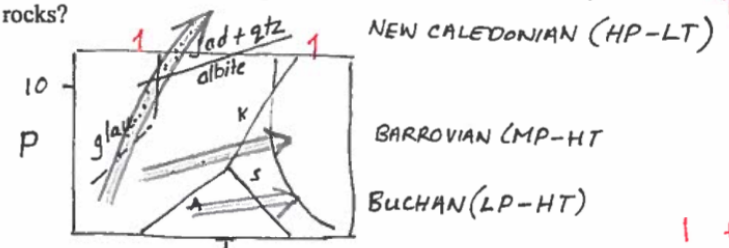
b) What are the plate tectonic environments where the different metamorphic field gradients can be formed?

c) Draw a sketch diagram showing the relationship between the PT paths, the geotherms, and the metamorphic field gradient, expected for a simple history of crustal shortening.

d) What metamorphic rocks are found in the Alps and what is the tectonic history indicated by these rocks?

3

a) Diagram



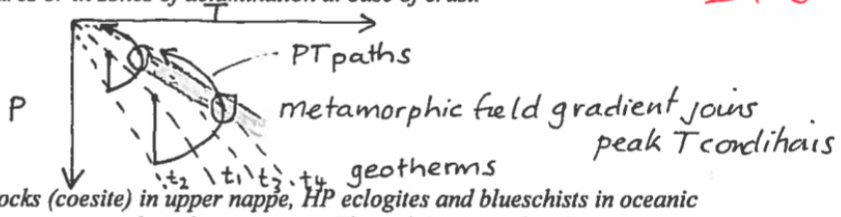
2 ½

b) HP-LT (new Caledonia) gradient is formed in subduction zones, MP-HT (Barrovian is formed in continental collision, or thickening; LP-MT (Buchan) is found in rift zones, volcanic arcs or in zones of delamination at base of crust.

1 for 1
1.5 for 2
2 for 3

3

c) Diagram



2

d) Series of UHP rocks (coesite) in upper nappe, HP eclogites and blueschists in oceanic nappe and lower pressure rocks in lower nappes. This subduction related metamorphism occurs before nappe stacking and crustal shortening. The nappe stack is overprinted by barrovian field gradient with ky and sill isograds. This is related to thermal relaxation and erosion after collision.