Centre For The Study Of Religion And Society,
Jadavpur University,
188,RAJA S.C.MALLIK ROAD,
Kolkata - 700 032, INDIA.
TEL.PHONE: 033 2414 6666
EXT.2164/0332414 / 0332414 6058 (O)
Email: rsainjdvu@gmail.com

Dr. Ruby Sain
Coordinator

02.01.2018
Date:

TO WHOM IT MAY CONCERN

This is to certify that Dr. Sumita Saha is attached with the MHRD sponsored UGC Project and she is working satisfactorily. I wish her success in life.

Ruby Sain 2/1/2018

Prof. Ruby Sain, PI,

EPGPATHSHALA UNDER UGC,

Department of Sociology,

Jadavpur University,

Kolkata-32.

Professor
Department of Sociology
Jadavpur University
Kolkata-700032

Link: URL: http://epgp.inflibnet.ac.in/viewf.php?category=1569

Sumita Saha

Centre For The Study Of Religion And Society,
Jadavpur University,
188,RAJA S.C.MALLIK ROAD,
Kolkata - 700 032, INDIA.
TEL.PHONE: 033 2414 6666
EXT.2164/0332414 / 0332414 6058 (O)
Email: rsainjdvu@gmail.com

Dr. Ruby Sain
Coordinator

Date:

05.02.2018

TO WHOM IT MAY CONCERN

This is to certify that Dr. Sumita Saha is attached with the MHRD sponsored UGC Project and she has worked satisfactorily. Her module: **M-24 Medical Practitioners approach to Religious Patients** has been uploaded on the EPGPATHSHALA website. I wish her success in life.

Ruby Sain 5/2/2018

Prof. Ruby Sain, PI.

EPGPATHSHALA UNDER UGC, Professor

Department of Sociology, Department of Sociology

Jadavpur University, Jadavpur University

Kolkata-32. Kolkata-700032

Link: URL:

Sumita Saha

Centre For The Study Of Religion And Society,
Jadavpur University,
188,RAJA S.C.MALLIK ROAD,
Kolkata - 700 032, INDIA.
TEL.PHONE: 033 2414 6666
EXT.2164/0332414 / 0332414 6058 (O)
Email: rsainjdvu@gmail.com

Dr. Ruby Sain
Coordinator

Date: 29.01.2018

TO WHOM IT MAY CONCERN

This is to certify that Dr. Sumita Saha is attached with the MHRD sponsored UGC Project and she has worked satisfactorily. Her module: **M-22 Pharmacology and Religion** has been uploaded on the EPGPATHSHALA website. I wish her success in life.

Prof. Ruby Sain, PI.

EPGPATHSHALA UNDER UGC,

Department of Sociology,

Jadavpur University,

Kolkata-32.

Professor
Department of Sociology
Jadavpur University
Kolkata-700032

Link: URL: [illegible]

Centre For The Study Of Religion And Society,
Jadavpur University,
188,RAJA S.C.MALLIK ROAD,
Kolkata - 700 032, INDIA.
TEL.PHONE: 033 2414 6666
EXT.2164/0332414 / 0332414 6058 (O)
Email: rsainjdvu@gmail.com

Dr. Ruby Sain
Coordinator

Date: 15.01.2018

TO WHOM IT MAY CONCERN

This is to certify that Dr. Sumita Saha is attached with the MHRD sponsored UGC Project and she has worked satisfactorily. Her module: **M-20 Community Medicine and Religion** has been uploaded on the EPGPATHSHALA website. I wish her success in life.

Ruby Sain, 15/1/2018

Prof. Ruby Sain, PI.

EPGPATHSHALA UNDER UGC,

Department of Sociology,

Jadavpur University,

Kolkata-32.

Professor
Department of Sociology
Jadavpur University
Kolkata-700032

Link: URL:

Sumita Saha

Centre For The Study Of Religion And Society,
Jadavpur University,
188,RAJA S.C.MALLIK ROAD,
Kolkata - 700 032, INDIA.
TEL.PHONE: 033 2414 6666
EXT.2164/0332414 / 0332414 6058 (O)
Email: rsainjdvu@gmail.com

Dr. Ruby Sain
Coordinator

02.01.2018
Date:

TO WHOM IT MAY CONCERN

This is to certify that Dr. Sumita Saha is attached with the MHRD sponsored UGC Project and she is working satisfactorily. I wish her success in life.

Ruby Sain 2/1/2018

Prof. Ruby Sain, PI.

EPGPATHSHALA UNDER UGC,

Department of Sociology,

Jadavpur University,

Kolkata-32.

Professor
Department of Sociology
Jadavpur University
Kolkata-700032

Link: URL: http://epgp.inflibnet.ac.in/viewf.php?category=1569

Sumita Saha

Centre For The Study Of Religion And Society,
Jadavpur University,
188,RAJA S.C.MALLIK ROAD,
Kolkata - 700 032, INDIA.
TEL.PHONE: 033 2414 6666
EXT.2164/0332414 / 0332414 6058 (O)
Email: rsainjdvu@gmail.com

Dr. Ruby Sain
Coordinator

Date: 02.01.2018

TO WHOM IT MAY CONCERN

This is to certify that Dr. Sumita Saha is attached with the MHRD sponsored UGC Project and she has worked satisfactorily. Her module: **M-01 Basic Understanding of Health and Religion** has been uploaded on the EPGPATHSHALA website. I wish her success in life.

Ruby Sain 2/1/2018

Prof. Ruby Sain, PI.

EPGPATHSHALA UNDER UGC,

Department of Sociology,

Jadavpur University,

Kolkata-32.

Professor
Department of Sociology
Jadavpur University
Kolkata-700032

Link: URL:

Sumita Saha

Centre For The Study Of Religion And Society,
Jadavpur University,
188,RAJA S.C.MALLIK ROAD,
Kolkata - 700 032, INDIA.
TEL.PHONE: 033 2414 6666
EXT.2164/0332414 / 0332414 6058 (O)
Email: rsainjdvu@gmail.com

Dr. Ruby Sain
Coordinator

02.01.2018

Date:

TO WHOM IT MAY CONCERN

This is to certify that Dr. Sumita Saha is attached with the MHRD sponsored UGC Project and she is working satisfactorily. I wish her success in life.

Ruby Sain 2/1/2018

Prof. Ruby Sain, PI.

EPGPATHSHALA UNDER UGC,

Department of Sociology,

Jadavpur University,

Kolkata-32.

Professor
Department of Sociology
Jadavpur University
Kolkata-700032

Link: URL: http://epgp.inflibnet.ac.in/viewf.php?category=1569

Sumita Saha

Subject	Geology
Paper No and Title	**Metamorphic and Igneous Petrology**
Module No and Title	Quantitative Geothermobarometry: P-T Evolution Paths of Metamorphic Rocks
Module Tag	XIV

Principal Investigator	Co-Principal Investigator	Co-Principal Investigator
Prof. Talat Ahmad ***Vice-Chancellor*** Jamia Millia Islamia Delhi	**Prof. Devesh K Sinha** Department of Geology University of Delhi Delhi	**Prof. P. P. Chakraborty** Department of Geology University of Delhi Delhi
Paper Coordinator	**Content Writer**	**Reviewer**
Prof. Pulak Sengupta Department of Geological Sciences, Jadavpur University Kolkata	**Prof. Sankar Bose** Department of Geology Presidency University, Kolkata	**Prof. Pulak Sengupta** Department of Geological Sciences, Jadavpur University Kolkata

Table of Contents

1. Introduction

Petrologists find it difficult to understand the evolution of metamorphic provinces unless the variables are quantified in terms of absolute numbers. The concepts of metamorphic zone, facies and grade give some qualitative ideas about the physical conditions of metamorphism, but any kind of modelling requires hard data. Thus, one needs to put absolute values for variables like pressure, temperature and fluid composition for a particular metamorphic rock. The quantitative estimation of pressure and temperature is known as geothermobarometry. As the terms "thermometer" and "baromemeter" are commonly used to determine temperature and pressure, the prefix "geo" relates those in favour of geologically relevant conditions. We all know thermometer and barometer are scientific instruments that work on simple principles. On the other hand, geothermometers and geobaromemeters are actually mineral reactions that achieve the state of equilibrium at particular T, P conditions leaving its imprint on the chemistries of participating minerals. Once such chemical attributes are known and thermodynamic parameters are chosen from reference database, we can actually measure the pressure and temperatures of metamorphism. The same principle applies to igneous process, but we will restrict our discussion on metamorphism.

Although things are presented simplistically, we now need to elaborate this aspect in a much broader way. The term "equilibrium" itself is of profound importance in thermodynamics and when we deal with geochemical thermodynamics, it becomes extremely crucial. Therefore, a background of geochemical thermodynamics is important to start with.

2. Thermodynamic background

The term "equilibrium" in metamorphic system involves two aspects, namely texture and chemistry. Chemical equilibrium is achieved in a system when there is no chemical potential gradient of any of the components present. So, in ideal situations, there should be no chemical zoning in equilibrated metamorphic system and all the minerals should be chemically homogeneous. In our experience, we can understand that such a situation is hardly possible as all the natural systems contain zoned minerals. Textural equilibrium, on the other hand, can be determined from the geometry of mutual grain contacts. However, determination of equilibrium state for a metamorphic system is easier said than done and one needs rigorous analysis of texture and chemistry of the mineral phases. As equilibrium condition is hardly possible in natural systems, one can wonder why we need to discuss all about it. It's true that total equilibrium is impossible in natural systems, but domain equilibrium is actually possible. It means that although there is an overall disequilibrium, there can be small domains (micro- to macro-scale) that exhibit the features (both chemical and textural) of equilibrium.

The concept of equilibrium is crucial in geochemical thermodynamics. The laws of thermodynamics can be converged for a system in equilibrium and several important thermodynamic system parameters like entropy (S), enthalpy (H), Gibbs Free Energy (G), Internal Energy (E) can be obtained. The Clapeyron's equation gives us the slope of any equilibrium reaction in terms of P and T as

$dP/dT = \Delta S/\Delta V$

where S and V are entropy and molar volume of the phases respectively.

Chemical composition of the phases is an important variable and solid solution phases show systematic compositional variation with respect to pressure and temperature. The parameter that takes this change into account is known as the distribution coefficient or

K_D. The equation of state of any system in equilibrium is expressed in the Vant Hoff's isotherm as

$\Delta G= \Delta H-T\Delta S+P\Delta V+ RT \ln K=0$

Now, ΔH, ΔS and ΔV are measurable properties of an equilibrium reaction. We have published data for such thermochemical parameters. K is known as equilibrium constant, which is a function of P and T only. In complex natural systems, more than 90% of metamorphic minerals are solid solutions. Therefore, K will be split into two terms, K_D and K_γ. For chemical equilibria with pure phases, K is equal to K_D and is a function of P and T only. $K_\gamma$is a function of P, T and composition of the solid solution minerals. Therefore, for equilibria involving solid solution phases, $K_\gamma$has to be evaluated independently.

$K = a_{Product}/a_{Reactant}$

Now, we are left with two unknown variables, namely P and T. If we can choose a suitable reaction which is insensitive to P, we can determine the T factor and vice versa. The suitable reaction for estimation of T or geothermometry is guided by the Clapeyron's equation. Reactions with high ΔS, high ΔH and low ΔV are good thermometers (Fig. 1) as they define steep dP/dT slopes (thus insensitive to P). Among the different types of metamorphic reactions, cation exchange reactions exhibit such qualities and are extensively used in all practical purposes. On the other hand, reactions with high ΔV, low ΔS and low ΔH are good geobarometers (Fig. 1) as they define much flatter dP/dT slope (and hence insensitive to T). Net-transfer reactions are suitable as they involve large change in molar volume. Although ideal geothermometers and geobarometers should be absolutely independent of P and T respectively (having perpendicular and horizontal dispositions in P-T plane!), such reactions are seldom possible. Thus, temperature values in all geothermometers depend on pressure and pressure values in all geobarometers depend on temperature values in all practical cases. Only thing we need to check that the dependence should be as minimal as possible.

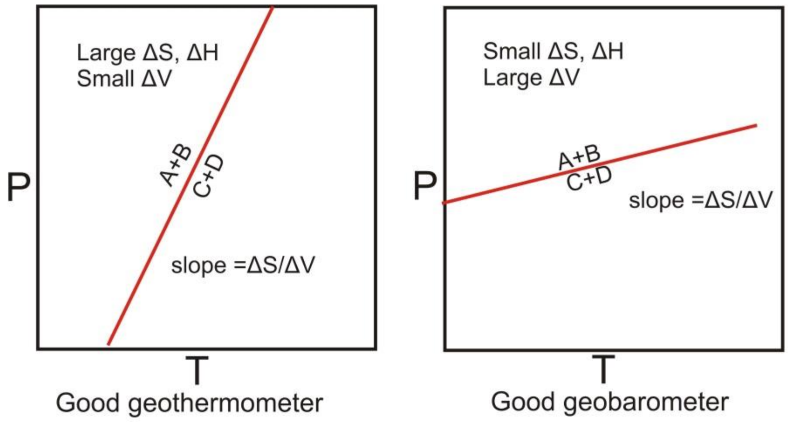

Fig. 1. Simple line diagrams illustrating reactions ideal for geothermometric and geobarometric studies.

3. Experimental backup

Once a mineral reaction is identified as suitable geothermometer or geobarometer, one has to use it as a model which can be utilized for number of geological conditions. This modelling of any specified reaction is done by laboratory experiment in which compositions of the reactant and product phases are measured in known pressure and temperature conditions. Once the reaction is experimentallymodelled and plotted in the lnK vs. 1/T plane, the values of ∆S, ∆V and ∆H can be extracted from the slope and intercept of the experimentally calculated regression line. The experiment should be reversed so that equilibrium should be reached from both directions (increasing as well as decreasing temperature sides) and the experimental curve is well-bracketed. We have to remember that this exercise is both expensive and time consuming, but give us very tight constraints on pressure-temperature dependence of any reaction. For example, Ferry and Spear (1978) experimented on the Fe-Mg exchange between coexisting garnet and biotite at 0.207 kbar and the temperature range of 550-800°C (Fig. 2).

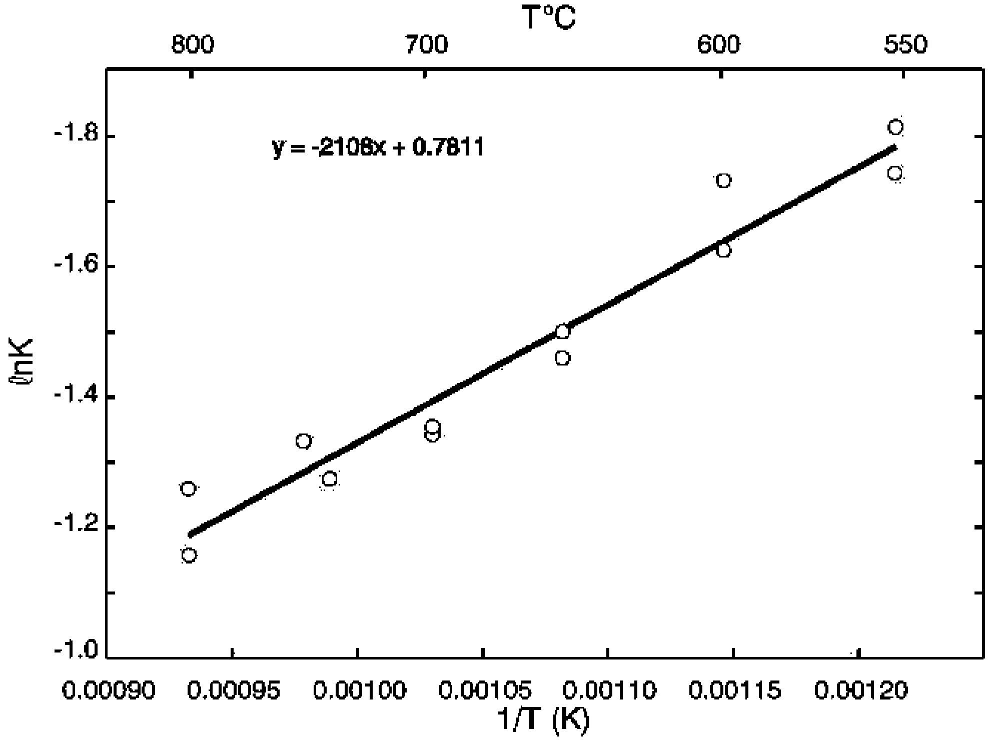

Fig. 2. Plot of lnK vs. 1/T values obtained in the garnet-biotite thermometric experiment by Ferry and Spear (1978) (after Ferry, J.M., Spear, F.S., 1978. Contrib. Mineral. Petrol.v 66, 113-117).

4. Types of Geothermobarometers

We have several options for estimating pressure and temperatures for natural rocks. For estimation of temperatures, the most common type of thermometers is *Exchange thermometer*. This works on the principle of temperature dependent cation exchange between two coexisting equilibrated minerals. This is known as ***Intercrystalline exchange thermometer***. The most common examples are Fe^{2+}-Mg exchange thermometer involving garnet and biotite, garnet and orthopyroxene, orthopyroxene and biotite and so on. As the molar volume changes for such reactions are very small and entropy changes are very high, these exchange thermometers are widely used as very reliable temperature sensors. Exchange of cation can also occur between two different crystallographic sites (octahedral, tetrahedral etc.). Therefore, distribution of such cation in different sites can be used as temperature sensor. This is known as ***Intracrystalline exchange thermometer***. In pyroxene grains, systematic partitioning of Fe^{+2} and Mg occurs between octahedral M_1 and M_2 sites.

Let us discuss about an example of exchange thermometry. One of the most used exchange thermometer is the garnet-biotite geothermometer. Ferry and Spear (1978) experimentally calibrated the exchange reaction

$Fe_3Al_2Si_3O_{12} + KMg_3Si_3AlO_{10}(OH)_2 = Mg_3Al_2Si_3O_{12} + KFe_3Si_3AlO_{10}(OH)_2$

Alm Phl Pyr Ann

Using well-bracketed experiments, they calculated the K values from compositions of coexisting garnet and biotite in each run. The K value eventually is expressed as

$K = K_D = [\alpha_{Pyr}^{Grt}/\alpha_{Ann}^{Bt}]/[\alpha_{alm}^{Grt}/\alpha_{Phl}^{Bt}]$

Assuming both garnet and biotite behave as ideal solid solution (γ=1)

$K_D = [X_{Mg}^{Grt}/X_{Fe}^{Bt}]/[X_{Fe}^{Grt}/X_{Mg}^{Bt}] = (Mg/Fe)^{Grt}/(Mg/Fe)^{Bt}$

Calculating the Mg and Fe contents from experimental runs, the values of K_D were plotted against 1/T which define a straight line

$\ln K_D = -2109/T(K) + 0.782$

From the measured values of K_D from unknown samples, we can calculate temperature (Fig. 3). This model is applicable for experimental pressure of 0.207 kbar. Since the reaction is relatively insensitive to pressure, this thermometer can be used for higher pressure at least up to mid-crustal conditions of metamorphism

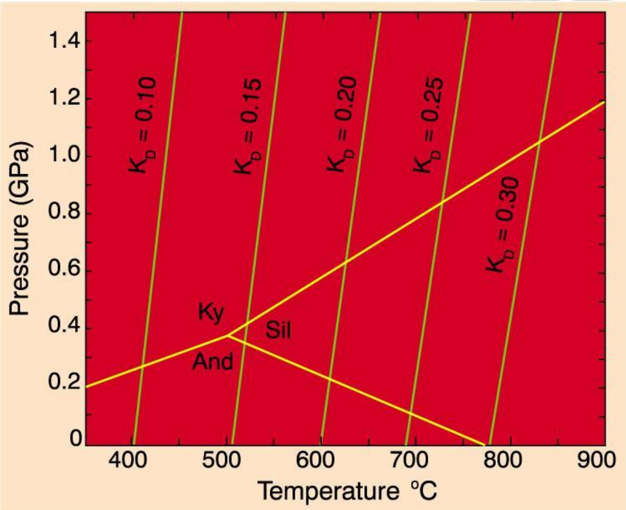

Fig. 3. P-T plot of the garnet-biotite exchange reactions at calculated K_D values obtained in the experiment of Ferry and Spear (1978) (after Spear, F.S., 1993. Monograph, Mineral.Soc. Amer. 799 pp).

Apart from cation exchange, mineralogical properties at varying temperatures are widely used as temperature sensors. The property of mixing and unmixing of end member components in a solid solution phase is also a temperature dependent process. The miscibility gap (solvus) of two end members of a solid solution phase can be expressed in temperature-composition space (T-X). Estimating the modal ratios of the two end members, we get the value of temperature from the curve itself. This is commonly known as *Solvus thermometry*. Experimentally well-constrained miscibility relationships between alkali feldspar – plagioclase feldspar (two-feldspar) and orthopyroxene-clinopyroxene (two-pyroxene) are commonly used as thermometers. However, we have to remember that the temperature estimated from the solvus is the minimum estimate of unmixing, while the actual temperature would be higher than the estimated value. Moreover, the parabola-shaped unmixing curve shows temperature maximum (consulate point) at the central part of the composition axis. Thus, for a given system, the maximum temperature is given by two end members when they show nearly equal modal volume. For example, in case of feldspar solvus, mesoperthite (where alkali and plagioclase feldspar show nearly equal modal volumes) provides the maximum temperature estimates (Fig. 4). Feldspar solvus thermometry is very common in practice and it gives independent estimate for varieties of metamorphic rocks. In some rocks of east Antarctica, ternary feldspar (albite-anorthite-orthoclase) solvus thermometer estimated temperature in excess of 1000°C. Apart from feldspar, other minerals like pyroxene, spinel can also be used for estimating temperatures.

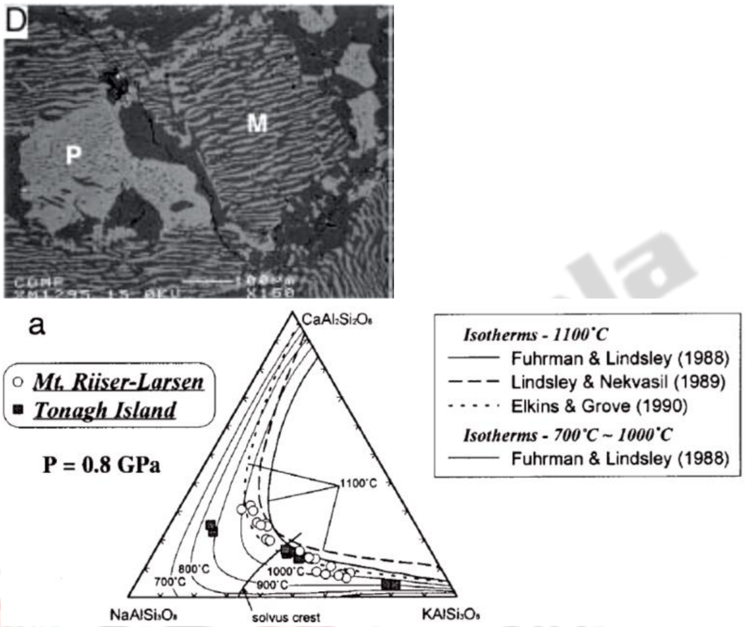

Fig. 4. Back scatter electron image of mesoperthite grains from UHT Napier Complex, east Antarctica. The coexisting feldspar compositions yield pre-exsolution compositions lying closely on 1000°C isotherm in the ternary feldspar plot (after Hokada, T., 2001. Amer. Mineral. v 86, 932-938).

With the advent of new analytical techniques and development of instrumental sensitivities, new types of thermometers are appearing day by day. Distribution of trace elements in minerals can also be used as reliable thermometers. This is known as *Trace Element thermometry*. For example, distributions of Zr in rutile, Ti in zircon etc. have proved to be very precise thermometers. These thermometers are experimentally calibrated like the more common exchange equilibria, but enhanced detection capacity of instruments like Electron Microprobe actually made it possible to use this type of thermometers.

For barometric estimation, we need to find suitable reactions that have large ΔV and we have already identified the net-transfer reactions as the most suitable pressure sensors. These are essentially solid-solid reactions. Although any net transfer reaction with small dP/dT slope can be used as good geobarometer, there are several well established equilibria like garnet-aluminosilicate-quartz-plagioclase (GASP), garnet-orthopyroxene-plagioclase-quartz (GOPS) and so on. Let's take the equilibrium reaction used in GASP. The reaction is

$$3\,CaAl_2Si_2O_8 = Ca_3Al_2Si_3O_{12} + 2Al_2SiO_5 + SiO_2$$

An Grs Ky Qtz

This is a well-known reaction delimiting the upper pressure stability limit of anorthite content of plagioclase. Koziol and Newton (1988) experimentally calibrated this reaction using reversal technique (Fig. 5). The best-fit line determined by the experimental plot has the equation

$P(MPa) = 2.28\,T(K) - 731.7$

Using the pure end members, the values of ΔS, ΔV and ΔH were determined, and the barometric equation now becomes

$P\,(MPa) = [-48.357 + 150.66T(K) + RT\ln K]/66.06$

Where $K = \alpha_{Grs}^{Grt}/(\alpha_{An}^{Pl})^3 = (X_{Grs}^{Grt})^3/(X_{An}^{Pl})^3$ assuming both garnet and plagioclase behave as ideal solution. In reality, none of these two behave like ideal solution and non-ideal mixing will introduce the activity coefficient term (γ) which is extremely difficult to calculate as it depends both on pressure and temperature. Using mathematical approximations, however, several activity models have been proposed for nonideal mixing of plagioclase, garnet and other solid solution phases. Despite limitations, this barometer is very popular among petrologists owing to its applicability in variety of rocks. The accuracy of this model is ±1.0 kbar.

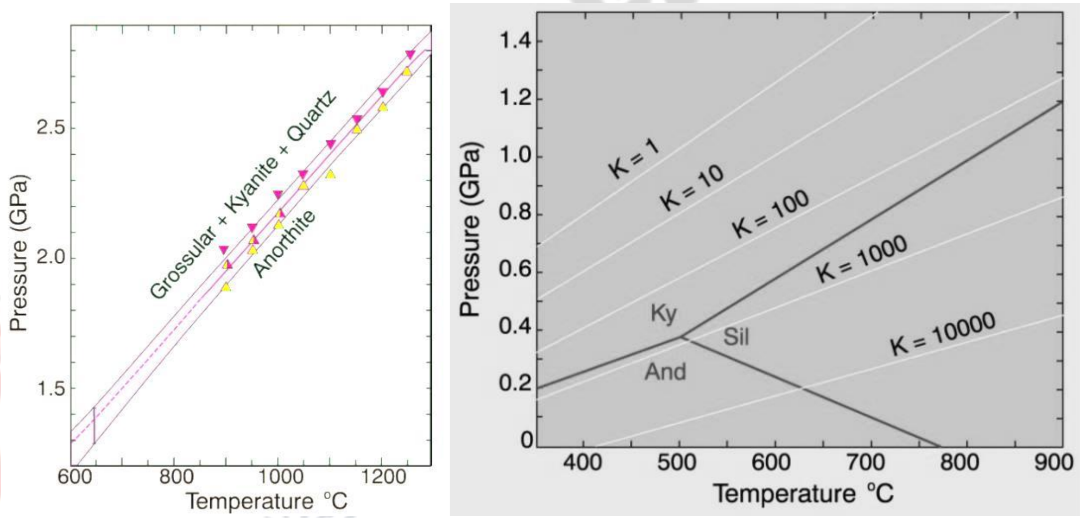

Fig. 5.Plot of the experimental run compositions for the GASP barometer of Koziol and Newton (1988). The pink triangles represent forward experimental runs, while the yellow triangles represent the reversed experiment (after Koziol, A.M., Newton, R.C., 1988. Amer. Mineral. v 73, 216-223). The position of the GASP equilibrium is shown in P-T plane for different calculated K values (after Spear, F.S., 1993. Monograph, Mineral.Soc. Amer. 799 pp.).

5. Use of multiple equilibria: simultaneous solution

Once we understand how a thermometer or a barometer works, we will be able to estimate P, T conditions of a metamorphic rock using suitable mineral assemblage. However, there is a small problem here. All the thermometric and barometric models require input values of pressure and temperature respectively, and we put approximate numbers in each case. Therefore, the obtained results are not accurate enough as they depend on our own understanding of the conditions of metamorphism. Although our experience drives us pretty close to the actual results, there is a very easy way to resolve this small problem. In a simple approach, we can use the technique of simultaneous solution. If we can choose two models one for geothermometric equation and the other for geobarometric equation from the same mineral assemblage, we will be left with two variables related by two equations. Let's put it using a simple example. If we have an assemblage of garnet-orthopyroxene-plagioclase-quartz which is stable in wide range of bulk compositions (pelitic, basic, psammitic) under granulite facies condition, we can choose the garnet-orthopyroxene geothermometer and garnet-orthopyroxene-plagioclase-quartz geobarometer to estimate T and P respectively. Using the same set of mineral compositions, we can independently estimate the P and T from these two thermobarometric equations. A somewhat similar approach is practised by many petrologists in recent times. This "average P-T" approach takes care of all the equilibrium reactions within a set of minerals given the activity corrected compositions. For example, the THERMOCALC software of Powell and Holland (1994) gives the option for such calculations. However, this approach is useful only if all the phases are solid ones. If there is any fluid-bearing phase (e.g. mica, amphibole etc.), fluid activity will also impart constraints on equilibrium conditions apart from pressure and temperature. Thus, unless fluid activity values are inserted, the entire exercise will lead to erroneous geothermobarometric estimation.

The pressure and temperature values must be unique for a particular metamorphic stage witnessed by a rock. However, different workers calibrate the thermometric and barometric equations using various starting compositions. Therefore, each model will yield separate estimate using same mineral data. We can use multiple models of same thermometry and barometry from assemblages with larger mineral sets. All the equilibria will plot in the P-T field to define a region rather than a unique point (Fig. 6). Moreover, we already understood that equilibrium is achieved in microdomain scale and there may be minor variation in chemistries of the participating minerals. This may result in variation in estimated P, T values using the same thermometric or barometric model.

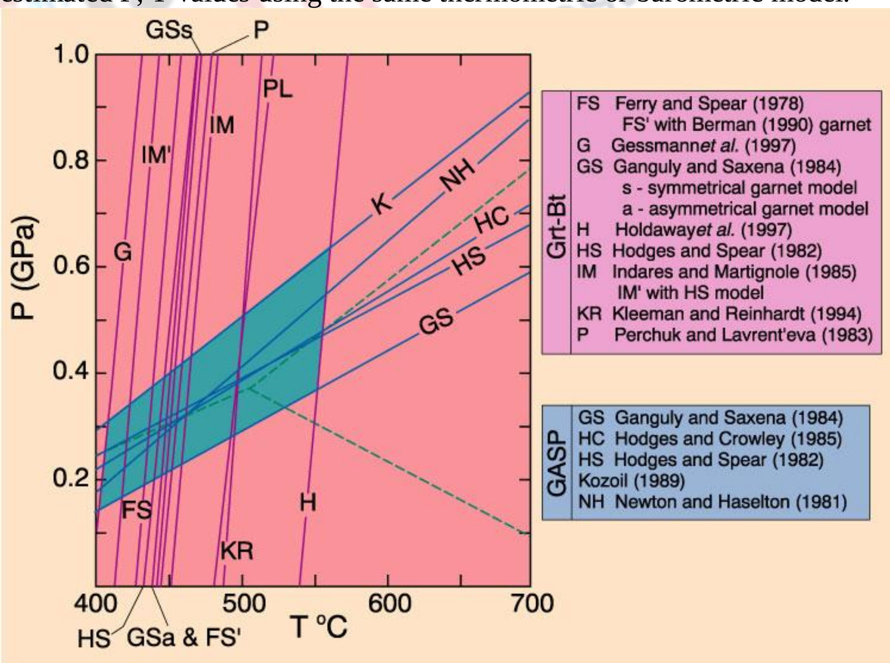

Fig. 6. Plot showing calculated results of Grt-Bt thermometry and GASP barometry using different models. When all the results are plotted, a common area represents the bracketed P-T estimate of the rock (after Winter, J.D., 2010. Prentice Hall, 702 pp.).

6. Composition zoning in minerals and quantified P-T path

The concept of pressure-temperature path of any metamorphic belt envisages the continuous movement of the P-T vector towards the arrow of time. This approach becomes more meaningful if we put absolute numbers along the vector. In a simple way, it means that we can estimate P and T values of several stages (prograde, peak or retrograde) of a single metamorphic continuum. If we are fortunate enough, the rocks may preserve equilibrium assemblages and the P and T values of each stage can be estimated. However, this rarely happens in natural mineral assemblages. We can make an alternative route to address this issue.

Compositional zoning in mineral may result during prograde stage (growth zoning) or retrograde stage (diffusion zoning). As a matter of fact, zoning in mineral itself proves equilibrium was not attained as a whole. However, if we go back to our earlier arguments, we can understand that equilibrium may not be attained as a whole, but there can be small epochs of domainal equilibrium. Suppose, we have an assemblage of garnet-plagioclase-biotite-quartz-muscovite, in which garnet contains inclusions of plagioclase of systematically variable composition (Fig. 7). Each coexisting plagioclase and garnet contact would imply domain of equilibrium. If we make a profile across the garnet (rim to rim), we will find gradual change in pyrope, almandine, grossular and spessartine components and each point along this line represents composition of garnet coexisted with plagioclase. We can use the GASP barometry to calculate pressure in each stage. If there is biotite along with plagioclase within the same zoned garnet, we can also use the garnet-biotite thermometry to calculate temperatures of equilibration at each stage of the same metamorphic continuum. Now if we take three representative zones from the garnet grain, one from the core, one from the rim and the third from the intermediate zone and calculate the P and T values, we will be able to find the locus of the P-T vector in absolute scale.

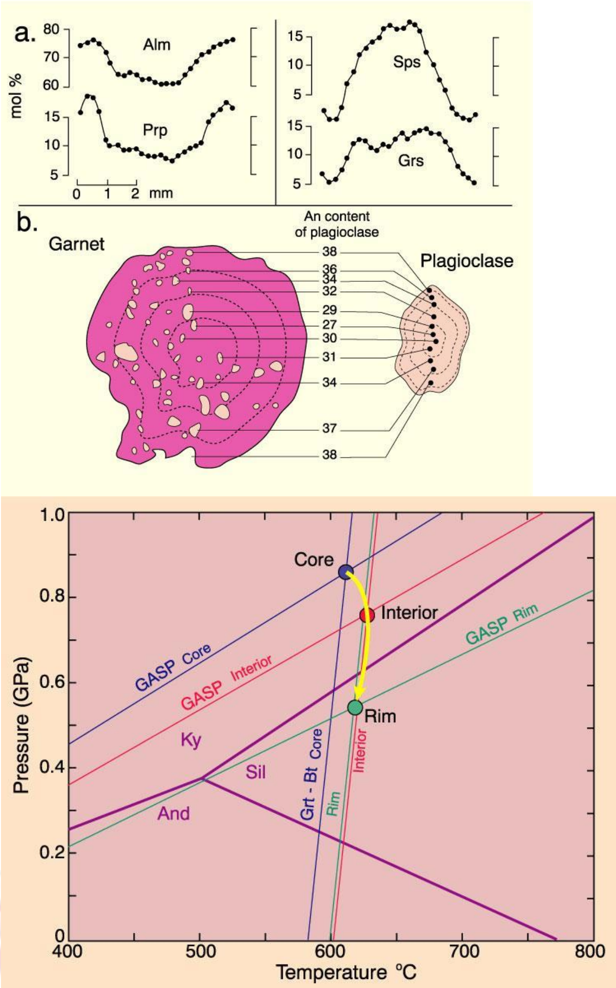

Fig. 7 Coexisting garnet and plagioclase show chemical zoning. Zoning profiles of garnet and An contents of plagioclase are also shown. The calculated P, T values for core-core, rim-rim and intermediate regions are plotted on a P-T grid which implies a steep decompressive P-T path (after St-Onge, M.R., 1987. Jour. Petrol., v 28, 1-22).

7. Sources of errors

We now understand that geothermobarometry is extremely powerful tool to quantify the metamorphic process. Like every tool we use, it has its own sets of inherent pitfalls. Therefore, we must be aware of these problems and take the note of caution before accepting the meaningful interpretations of the estimated values.

(1) The fundamental assumption is that mineral phases form equilibrium assemblage. Although it is possible to prove an assemblage not in equilibrium, it is impossible to prove otherwise. So, we need to check the textures and try to locate the domains of local or mosaic equilibrium. Crossing tie-lines for assemblages or element partitioning in mineral pairs provide indirect check on possible equilibrium features. Therefore, non-fulfilment of a set of criterion aimed to verify disequilibrium in a rock provides indirect check on equilibrium condition.

(2) Many thermometers have limited P-T span. For example, the Grt-Bt model was calibrated at different compositions by different workers. Ferry and Spear (1978) calibrated for garnet with low-Ca and Mn and biotite with low Al^{VI} and Ti content. Hodges and Spear (1982) and Perchuk and Lavrenteva (1981) estimated higher T as they introduced grossular correction in garnet. Solvus thermometers are more useful at higher T than lower T when compositions are located on the steep gradients of the solvus.
(3) Temperature values depend on K_D which is expressed as the proportion of Fe and Mg in most of the exchange thermometers. Fe in such calculation should ideally be considered as Fe^{2+}. Microprobe analysis of minerals measures total Fe without discriminating Fe^{2+} and Fe^{3+} out of the total iron. We can actually do this using wet chemical analysis or Mössbauer spectroscopy, but usually those are not done for routine analysis. Instead, we normally follow stoichiometric charge balancing from ideal structural formulae of a particular mineral to distribute total Fe into Fe^{2+} and Fe^{3+}. This is to some extent useful for calculating the actual Fe contents in K_D. Unless such a correction is made, the measured temperatures may be underestimated in the tune of 100°C.
(4) Peak temperature is seldom estimated due to resetting of cations during retrogressive metamorphism. Temperature recorded during cooling is called *blocking* or *closure temperature*. Since most of the cation exchange thermometers have blocking temperature below granulite facies condition, these usually give reset temperatures. Degree of resetting of cation exchange thermometers depends on diffusion rate which again is a function of grain size. To avoid this, thermometry should be applied to such mineral pairs showing high modal proportion and occurring as coarse blasts particularly where cooling rate is slow. Recovery of peak temperature is possible using the convergence technique or fossil thermometry.
(5) Chemical zoning can provide useful information of P-T history. Unfortunately, growth histories are commonly lost for potentially zoned minerals above 600°C. Therefore, compositional profiles should be carefully interpreted to ascertain which portion is in equilibrium with the matrix.
(6) Most calculations are based on experimental or thermodynamic database. Our knowledge of mineral thermodynamics is very limited on many occasions. Lack of volume correction, use of poor mixing models, use of un-bracketed experimental data -all provide uncertainties which seriously damages merit of calculation.
(7) Application of a particular experimental equilibrium to extreme high or low P-T conditions necessitates an extended projection of original reaction slope to unrealistic domain beyond critical limits.
(8) Structural modifications of certain phases provide unconstrained phase chemical data. Experimental data on sapphirine stability suggest the occurrence of a metastable disordered state, while natural sapphirine is always ordered phase. So, thermodynamic data using experimental sapphirine does not give reliable P-T estimates for assemblages containing natural sapphirine.

8. Retrieval of peak temperature

Retrieval of peak metamorphic temperature is a challenging task and many high temperature rocks were previously classified as average temperature ones. Fe-Mg cation exchange is very fast and once a rock undergoes retrogression from high temperature condition, the diffusion of Fe and Mg changes the K_D value. Therefore, we get the temperature values close to the blocking temperature. There are several ways to retrieve the peak temperature.

One such way is to texturally identify key mineral assemblages whose presence or erstwhile presence (texturally proved) unanimously imply certain high temperature brackets. Frost and Chacko (1989) discussed several such textures which they termed "*fossil thermometers*". Examples of such fossil thermometers are exsolution of pyroxene (inverted pigeonite) in metamorphosed ironstone, exsolution of Fe-Ti-Al oxides in metapeliticgranulites etc. The other approach could be use of an independent temperature sensor. Thus, Al-in orthopyroxene can be used as an independent sensor along with Grt-Opx thermometer (Harley and Fitzsimons, 1994; Pattison et al., 2003). Since Al is known to have extremely low mobility even under high temperatures, this can be used to retrieve the peak temperature (and pressure) conditions. Pattison et al. (2003) showed that using such correction, temperature estimates from garnet-orthopyroxene bearing rocks can be increased more than 100°C (Fig. 8).

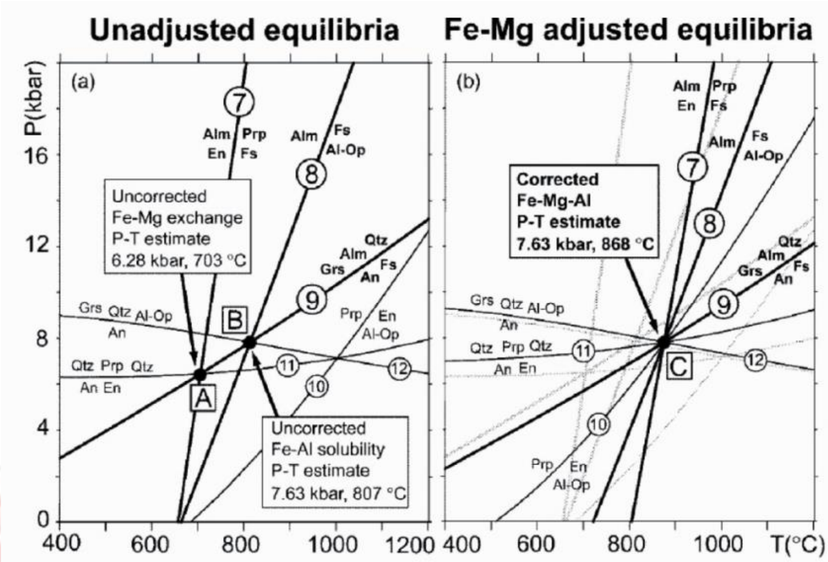

Fig. 8. Calculated phase diagrams for the Grt-Opx-Pl-Qtz assemblage. The left hand figure represents calculated invariant points for uncorrected estimates for Grt-Opx and Fe-Al in Opx thermometry. The right hand figure shows the corrected unique solution for P and T. Note the converged peak temperature is >150°C higher than the uncorrected Grt-Opx thermometer (after Pattison, D.M., Chacko, T., Farquhar, J., McFarlane, C.R.M., 2003. Jour. Petrol., v 44, 867-900).

9. Internally consistent database and calculations based on software

Computation of pressure and temperature values has traditionally been done using calculators and taking the thermodynamic parameters from published data tables. Workers up to 1980s struggled while computing the activity-composition relationships from very long and complex equations. The estimated values often could not be replicated by other workers because the thermodynamic parameters were chosen randomly from the-then existing data tables. During the 1980s, some of the petrological groups published thermodynamic data which are internally consistent. As a first step, this effort drastically reduced the uncertainty of calculations that was imparted by multiple sources of thermodynamic data. These internally consistent thermodynamic datasets were later packaged into computer softwares. These softwares could perform all the hard work of computation and were capable of producing graphical display of the results in terms of phase diagrams. Some of these softwares like THERMOCALC, PERPLEX, THERIAK-DOMINO, TWEEQ (Fig. 9) are extremely popular as these are free to use and user-friendly. With the dramatic improvement of computer performance in recent years and continuous upgradation of these softwares, major task of thermobarometry is now dependent on computer which obviously can handle thousands of data at one go.

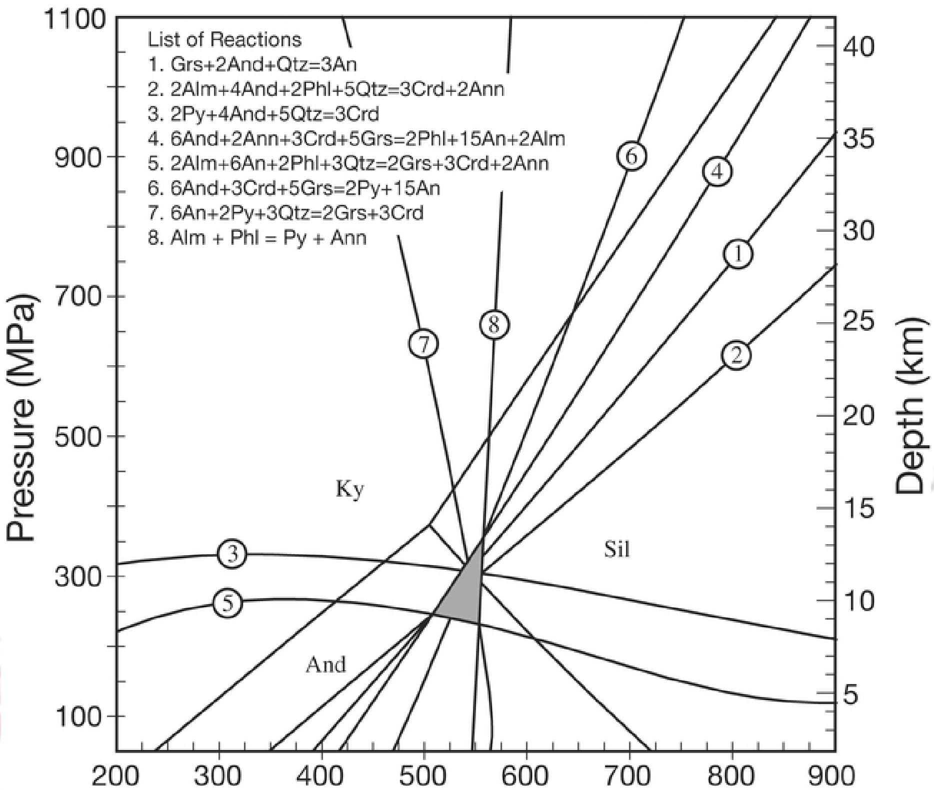

Fig. 9. An activity-corrected plot of equilibrium reactions involving a set of minerals calculated after the software TWEEQ. Note the grey triangle representing the P-T field of the equilibrium mineral assemblage.

10. Phase equilibria analyses

As the computer-aided thermobarometric calculations made our life easier, there has been an effort to approach much more complicated petrological problems. The concept of P-T path made a lasting impression in quantified petrology, but there was one problem. The petrogenetic grids were constructed on some model bulk compositions which must remain constant throughout the entire evolutionary history of the metamorphic terrane. In nature, however, we have diverse bulk compositions and even if we choose any of such a bulk, it may change during the course of metamorphism. Modern day computers are capable enough to calculate phase relations using diverse bulk compositions and produce graphic display of the results. Softwares like THERMOCALC, PERPLEX, THERIAK-DOMINO provide excellent opportunity by constantly updating the thermodynamic data base, greater flexibility in choosing the right solution models and better graphic display. We can now construct a P-T diagram (popularly called pseudosection) using a specific bulk (defined by user either from whole rock chemistry or by image/modal analysis of reaction domains within a rock) in chemical systems that closely resemble the nature. The other advantage of such phase diagrams over traditional petrogenetic grid is that they plot the high variance stability fields unlike the univariant and invariant equilibria plotted in the latter. Therefore, we can locate the different stages of metamorphic continuum from the stability fields of the same assemblages in the phase diagram. To further pinpoint the P, T conditions for a particular stage (peak, retrograde or prograde), we have the additional options to plot the compositional isopleths of any solid solution phase. Intersection of any two such independently variable isopleths will give the exact P-T coordinates of any specified stage of metamorphism (Fig. 10). We can also use mineral modes and many other properties to make our calculations as robust as possible.

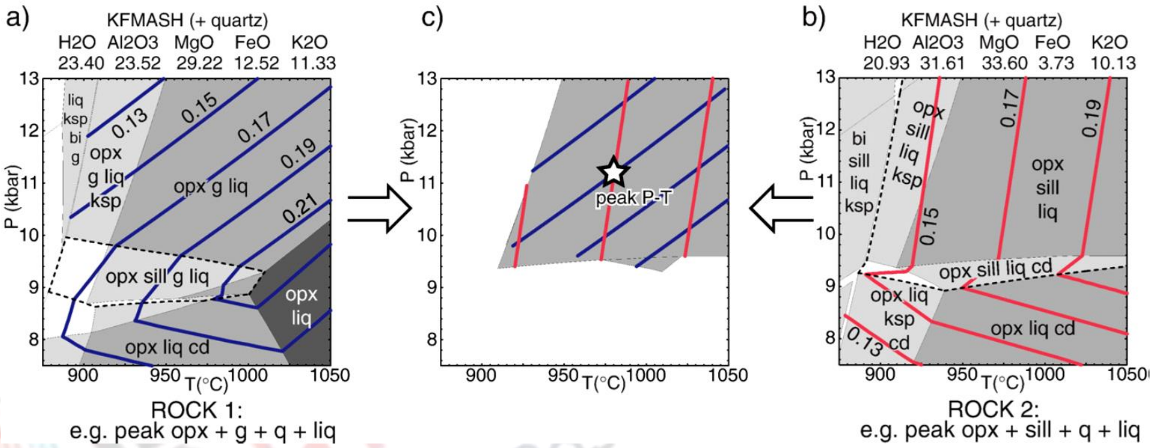

Fig. 10. An example of how one can estimate peak metamorphic conditions for UHT rocks using pseudosections in conjunction with the Al isopleths of Opx. Assuming the Rock 1 (a) has a peak mineral assemblage of Grt+Opx+Qtz+melt, the P–T stability limits for this assemblage are defined graphically by this corresponding field. Similarly, Rock 2 (b) shows the stability limits of assumed peak Opx+Sil+Qtz+melt defined graphically in P-T space by the corresponding pseudosection. Each pseudosection can be contoured for aluminium content of Opx. Rock 1 and Rock 2 are assumed to have maximum values of 0.17 (Al/2 in Opx on 6 oxygen basis), corresponding to a P-T line (contour) within the peak assemblage fields. By overlapping the peak assemblage fields and the contours, (c), we can arrive at a constrained estimate of the exact metamorphic P-T conditions (after Kelsey, D.E., 2008. Gond.Res, v 13, 1-29).

Frequently Asked Questions-

Q1. What types of metamorphic reaction will be ideal for geothermomtery and geobarometry?

Ans. A good geothermometric reaction should have minimum dependence of pressure and plot at high angle to the T axis in a P-T diagram. As demanded by the Clapeyron's slope, such a reaction should have high ΔH and ΔS and low ΔV. Cation exchange reactions are considered to be ideal as they require very negligible change in molar volume. Therefore, reactions like Fe-Mg exchange equilibria involving pairs like garnet-biotite, garnet-orthopyroxene etc. are good geothermometers.

A good geobarometer likewise should have minimum dependence of temperature and plot at high angle to the P axis in a P-T diagram. Such a reaction will have low ΔH and ΔS and high ΔV. Net-transfer reactions are ideal to fulfil these criteria and considered as good geobarometers. Reaction involving garnet-plagioclase-aluminosilicate-quartz (GASP) is an example of such a good geobarometer.

Q2. What do you understand by 'closure temperature' for a geothermometer? How can you retrieve peak temperature estimates from high-grade rocks?

Ans. Diffusion related exchanges require suitable energy input so as to complete the process in finite time scale. Reactions involving cation exchange, i.e. exchange thermometers, work on this principle. The composition at the equilibrium is a direct function of temperature and we get this temperature value after measuring the compositions of coexisting mineral phases. As all the minerals undergo retrogressive metamorphism after attaining the peak temperature, diffusion of elements again sets in and the compositions of the coexisting minerals change. As the temperature decreases, the rate of diffusion gradually drops until a critical value of temperature is achieved below which practically no diffusion takes place. This critical temperature is called the closure temperature. This value depends on the mineral pairs. For example, the closure temperature for a garnet-orthopyroxene pair is higher compared to the garnet-biotite pair. As a result of this resetting near the closure temperature, all the exchange thermometers show lower temperature estimates than the actual peak temperature.

The effect of late exchange and resetting can seriously underestimate the temperature estimation of high-grade rocks. To avoid this, one can employ several other methods: (1) identification of key textures like exsolution lamellae in pyroxene as fossil thermometers that can provide important clues regarding the very high temperature of unmixing, (2) Retrieval of the peak temperature using convergence technique as outlined by Fitzsimons and Harley (1994) and others, (3) Reliance on cation exchange reactions in which diffusion of a particular element is very slow under falling temperature conditions, like Al in orthopyroxene.

Q3. Why do we get different temperature estimates from same set of chemical data but different models?

Ans. Ideally, we should get same temperature estimates from a given set of mineral chemical data. But our experience shows otherwise. This is because the models formulated by different workers involve thermochemical parameters of minerals which can be chosen from available database. Such data for a single mineral varies for different database and as a result their choice can affect the temperature estimation. For garnet-biotite thermometry, solution models of biotite involving Al and Ti would always give higher temperature estimates than simple Fe-Mg exchange model outlined by Ferry and Spear (1978).

Q4. Explain why solvus thermometers never give the actual metamorphic temperature?

Ans. Solvus thermometry works on the principle of temperature dependent unmixing. So these equilibria will always yield the temperature of unmixing from an unknown peak condition. Even if the temperature estimated from a solvus thermometer is really high, it will be the temperature of unmixing and not the actual temperature of metamorphism. Therefore, such temperatures should always be regarded as the minimum temperature of the peak condition.

Q5. Element compositions of the following phases are obtained from EPMA data of charnockite.

Fe^{+2}-Gt	1.729	Fe^{+2}-Opx.	0.657	Mg-Bt	1.981
Mg-Gt	1.209	Mg-Opx.	1.224	Fe-Bt	0.720
Ca-Gt	0.058	Mn-Opx	0.001		
Mn-Gt	0.016				

Calculate the peak metamorphic temperature using the equilibrium assemblage Grt-Opx thermometer assuming peak pressure of 8 kbar. Also calculate the retrograde temperature using Grt-Bt assemblage.

Lee and Ganguly (1988) model for Grt-Opx thermometry

$T\ (C) = [\{1971+11.91P+3000(X_{Ca}Grt + X_{Mn}Grt)/1.9872\}/(\ln K_D+0.96)]-273$

Where $K_D = (Mg/Fe)\ Grt/(Mg/Fe)\ Opx$

Ferry and Spear (1978) model for Grt-Bt thermometry

$T\ (C) = 2109/\ (\ln K_D+0.782)\ -273$ where $K_D = (Mg/Fe)\ Grt/(Mg/Fe)\ Bt$

Ans. Temperature using the Grt-Opx thermometer is 811ºC and Grt-Bt thermometer is 707ºC.

Multiple Choice Questions-

1. A good geobarometric reaction should possess
   a. High ΔS
   b. High ΔH
   c. High ΔV
   d. None of the above

   Ans. c
2. The following is an example of trace element thermometry
   a. Mg in biotite
   b. Ti in zircon
   c. Ca in garnet
   d. Al in pyroxene

   Ans. b
3. He following is an example of fossil thermometer
   a. Al isopleth of orthopyroxene
   b. Zrn distribution in rutile
   c. Pyroxene exsolution in metamorphosed ironstone
   d. Coexistence of garnet and biotite

   Ans. c
4. Calculation of temperature and pressure can be more precise if we use thermodynamic database which is
   a. Internally consistent
   b. Chosen from multiple sources
   c. Chosen from experimental results only
   d. None of the above

   Ans. a
5. Quantitative P-T path can be established from mineral pairs showing
   a. Homogeneous compositions
   b. Chemical zoning
   c. Textural equilibrium
   d. Replacement texture

   Ans. b

Fill in the Blanks-

1. Al content in _____ is a reliable thermometer in high temperature rock.

Ans. orthopyroxene

2. Feldspar thermometry is an example of ____ thermometry.

Ans. solvus

3. Activity of any component in an ideal solution equals to the ______ of that component.

Ans. Mole fraction

4. A phase diagram calculated at a fixed bulk composition is commonly known as _______.

Ans. pseudosection

5. Blocking effect results from _______ of cations due to retrogression.

Ans. Resetting

Suggested Readings:

1. Philpotts, Anthony R., & Ague, Jay J. (2009). Principles of igneous and metamorphic petrology, 2nd Edn. Cambridge University Press. ISBN: 0521880068, 978-0521880060.
2. Winter, John D. (2001). An Introduction to Igneous and Metamorphic Petrology, 1st Edn. Prentice-Hall Inc., New Jersey. ISBN: 0132403420, 978-0132403429.

Structuralism in Geography

Subhajit Das

Component-I(A) - Personal Details

Role	Name	Affiliation
Principal Investigator	**Prof. Masood Ahsan Siddiqui**	Department of Geography, Jamia Millia Islamia, New Delhi
Paper Coordinator, if any	**Dr.Taruna Bansal**	Department of Geography, Jamia Millia Islamia, New Delhi
Content Writer/Author (CW)	**Dr. Subhajit Das**	Assistant Professor Department of Geography Presidency University Kolkata
Content Reviewer (CR)	**Dr. Abhay Krishna Singh**	Assistant Professor Department of Geography Ranchi College, Ranchi University, Ranchi
Language Editor (LE)		

Component-I (B) - Description of Module

Items	Description of Module
Subject Name	Geography
Paper Name	Geographical Thought
Module Name/Title	**Structuralism in Geography**
Module Id	GEOG/24
Pre-requisites	
Objectives	To understand the **Structuralism in Geography**
Keywords	**Structuralism**, Geography

Structuralism in Geography

Subhajit Das

I. Introduction:

The term structuralism has been widely used in different fields of social sciences and humanities. It witnessed multifaceted contribution of several scholars from different subject domains like linguistics and semiotics, cultural anthropology, literary studies, psychoanalysis and others. However, the input of the French thinkers and philosophers was found to be dominant in deciding over the discourse line of structuralism (Warf, 2006, pp. 464-465). The initial development in the concept of structuralism basically came from the contribution of European scholars during the early twentieth century followed by the thinkers from Prague, Moscow and Copenhagen schools of linguistics. The structural linguistics of Ferdinand de Saussure (1857-1913) actually paved the journey of structuralism which was later on applied in a diverse range of fields based on different other perspectives and contexts with the advancement of time and discourse. His philosophy was based on the understanding about the relative meaning of the words or linguistic signs depending on the essentially different opposite meanings which are called as the binary oppositions since they appear to be in pairs. The concept of structuralism revived back its significance during the 1950s with the philosophy of structural anthropology led by French anthropologist Claude Lévi-Strauss who instigated the propagation of the structuralist movement in France. The structuralists advocated that the explanation of the observed phenomena should be claimed from the general structures that underpin the human culture and the behavioural pattern of the human agency in shaping the society in a particular manner. The general structures are not supposed to be identifiable within the surface properties of such phenomena and thus, require a more in-depth analysis to reveal that out (Johnston, 1986, pp. 97-135, Lippuner and Werlen, 2009). Structuralism is, therefore, itself a theory as well as the methodology which is guided by the research interest of the investigator in exploring the underlying structure with proper logic and justifications (Warf, 2006, pp. 464-465). The structuralist movement in France strongly influenced the works of psychoanalyst Jacques Lacan and other eminent writers like Louis Althusser and Nicos Poulantzas who were the pioneers in unfolding the essence of structural Marxism philosophy – one of the various forms of Marxism. Their analytics on the power structure and the process left the imprint of structuralism primarily in the domains of economic, political and urban geography (Gregory et al., 2011, p. 725). Later on, during 1970s geographers took several opportunities in the light of structural Marxism to strongly critique the empiricist projects and the dimensions of spatial science which geographers used to manifest by the application of scientific techniques like cartography. Such critiques also include the activities of the humanistic geographers who used to challenge the limits of interpretations that come out of the spatial science analytics. The Marxist geographers were against the naive approach of understanding the human agency and in favour of unpacking the depth of social structure and the spatial economy by means of the structural properties (Warf, 2006). With time, the legacy of structuralism in geography was largely left behind with the emergence of the philosophies like structuration, realism, and post-structuralism. However, the importance of linguistic studies, literary discourse, and analytics of power structure has remained unchallenged.

The present material will first focus on the different contexts of structuralism based on the contribution of different scholars in their respective subject domains and finally will discuss on how the geographers adopted the essence of structuralism in dealing with various geographical phenomena belonging to the different branches of geography.

II. Major contexts of structuralism:

The structure is something which is strongly dependent on the relations. There have been some typical forms of structuralism by means of the scholars' contribution at different contexts in revealing the structural underpinning of various phenomena. Such contexts include the language, signs and linguistics; culture and structural anthropology; literary theory, literature and mythologies; and psychoanalysis. Such contexts in the light of structuralism are summarized below-

A. *Language, signs, and linguistics –*

The meaning of structuralism starts with the concept of structure, the linguistic meaning of which is dependent on the mythos and logos that are considered to be the meta-dimensions of language. Ferdinand de Saussure who was first to put forward the structural linguistics suggested conceiving the language as a system. The language is expressed in terms of some signs which immediately start with the spoken language. Therefore, signs do not have any relation with the sound. Signs are consisted of two parts- signifier and signified. The first one is the expression and the second one is the content. Signs are the unifiers of both of these two to reflect a particular meaning, although, in the theory of language, Saussure considers signs to be in the arbitrary position because signs are derived from the historical and social convention and the resultant tradition of the communities. It is the community of the language who decides over the formation and creation of the signs. Therefore, signs neither reflect anything external nor anything about the internal relationship between signifier and signified, instead those represent the internal connections that define the relationship among the signs. A sign is constituted based on how it is different from the other sign. The meaning depends on such difference of signs from one another. Saussure emphasized more on the underlying structural system of language (*langue*) rather than the use of the language (*parole*).

The work of Saussure influenced many linguistic scholars between World War I and II. For instance, in United States Leonard Bloomfield theorized his own version of the structural linguistics like Louis Hjelmslev from Denmark. Some others like Roman Jakobson and Nikolai Trubetzkoy who were basically from the Prague school of linguistics also continued the project of Saussure. However, during the 1950s the structural linguistics of Saussure was abandoned because of strong criticism.

B. *Culture and Structural Anthropology –*

Claude Lévi-Strauss, who has received a wide recognition to be considered as the father of structuralism, was mainly inspired by the works of Roman Jakobson and Nikolai Troubetzkoy from the Prague school of linguistics along with other scholars like Emile Durkheim and Marcel Mauss. He continued to carry on the legacy of Saussure's structuralism during the 1950s by applying the model of structural linguistics in the domain of structural anthropology. While putting more emphasis on unfolding the underlying pattern of human thought process to develop a culture, he considered that the processes do not determine a culture, rather operate within it. According to the theory of structural anthropology, the meaning is believed to be produced and reproduced within the culture because of the practices, activities, and phenomena that serve the system of signification. Strauss's areas of work mainly include the cultural phenomena like mythology, kinship, and food preparation.

He was strongly influenced by the Prague school of linguistics while deriving the concept of binary contrasts or the binary opposition which briefly states that the meanings are not absolute, but a relative that could be understood with the help of the structured relationship among the elements of a cultural system. All the terms are supposed to generate something opposite of what is being meant. It signifies that in human understanding there is no particular meaning or value of any element; rather it depends on the meaning of the other elements or the opposites. For example, to know the meaning of hot, one has to know the meaning of the opposite difference that is cold. To study a particular thing, it is needed to study the related and associated things in a broader structural framework.

In his theory of structural anthropology, Strauss argued that the grammatical of culture in form of kinship, myth, and language is based on the structured codes and the hidden rules of a behavioural pattern that guide the practitioners of a particular culture. Such codes and hidden rules govern the participants to make their culture different from the others (Lévi-Strauss, 1973). The very method what he proposed to unveil such kind of codes and laws is to identify the meanings based on the binary opposition. Strauss found that the exchange of concepts between families, particularly in the exchange of women is a very important concept, upon which he proposed the universal codes and laws of exchange in society (Rendtorff, 2014, pp. 121-147). It actually means that the basic structure of the human thought process always remains same across all the cultures based on the understanding of binary opposition (Winthrop, 1991).

Many scholars were influenced by the structural anthropology from different parts of the world. For instance, Maurice Godelier and of France came up with a new idea where they combined Marxism with the structural anthropology. Apart from them, Rodney Needham and Edmund Leach from Britain, Marshall Sahlins and James Boon from the United States are some of the names of scholars whose academic contribution to reflect the influence of structural anthropology. The philosophy started facing strong challenged during the 1980s because of its inability to verify the assumption of structural universality of the human mind and the exclusion of impacts of human agency over the basic structure of culture (Lett, 1987, Rubel and Rosman, 1996). However, the importance of considering the fundamental structure of human culture remains unturned.

C. *Literary theory, literature and mythology* –

Ronald Barthes (1915-1980), who was a professor of literature in France and a literary critique as well, has a significant contribution in the field of literature, literary discourse and the study of myths and mythologies. He adopted the essence of structural linguistics and structuralist approaches to interpreting the science of literature and language, especially in the analysis of writings and signs. His proposition was to unfold the relationship between signs, writings and the reality, particularly in the context of literature, poetry and the discourse of mythology in terms of language. Barthes put more emphasis on studying mythology not only in the fields of anthropology and religion but also in every sphere of the society, especially the contemporary one. According to him, myth is not actually defined by the content what it bears, instead, it is the way in which the context tries to convey the message in the society and also to maintain the truth and justification of the content which is being represented by the signs. In the line of de-Saussure, Barthes argued that the myths are to be considered as parole (signifier) rather than langue (signified) because it is the signifier that develops the system of signification and not the content that is signified by the myth. Anything which is developed on the basis of parole could be promoted as the discourse. Therefore there is every possibility to start with a new of discourse on individual myths. Therefore there can't be a particular rule to formally limit a myth to bear its content. It actually led him to establish a concept of generalized semiotics on the basis of which anything in the society could be considered as a myth and mythology (Rendtorff, 2014).

In his book Mythologies (1972), Barthes combined the generalized approaches of structuralist and the semiotics to the analysis of myths and mythologies in the society. While doing that, by virtue of the nature of his approach, he also combined Marxism to criticize the ideology of bourgeois and petit-bourgeois in terms of their basic structure of myth in which they used to live in and live by. In this way, he was strongly influenced by Sartre's existentialism which led him to take over the elements of unauthentic life to criticize the ideological superstructure of the society. It implies that his approach of structuralism and semiotics in assessing the mythical objects in the society has a critically political function to show the myths of daily life in the society expressed in different forms of publications and literature.

D. *Psychoanalysis* –

Jacques Lacan (1901-1981) who was basically a French psychoanalyst and a psychiatrist as well received a wide range of academic recognition in the domain of psychoanalysis as he applied the structuralist approach as his working method of analysis. However, his influence is more prominent in the writings of leading French intellectuals who later on, contributed significantly to the development of post-structuralist philosophy. Lacan is well-known for the development of Freudian psychoanalysis approach based on the contemporary theoretical basis. He put forward the scientific methodological approach of psychoanalysis in theory and praxis. According to him, the concept of the unconscious is a very important component in psychoanalysis and that is why he was strongly influenced by the domains like linguistics, anthropology, psychology, and mathematics while designing the line of action of psychoanalysis as a generalized theory to study about humanity. He was also inspired by the scholars of phenomenological discourse like Hegel, Sartre, Heidegger, and Merleau-Ponty which is reflected in his analytical proposition which claims the theoretical distinctions between the concepts like imaginary, symbolic and real.

In his Freudian school of psychoanalysis he emphasized on revealing the philosophical interpretation of the major concepts like desire, sexuality, subject, phallus, pleasure, libido, unconscious, symbolic order and the sinthom. According to him, the relations of human beings with their desires could be seen as a social phenomenon. Therefore, it is quite inevitable that the meaning of the social interactions and relationships would certainly reflect the structure of the human desires. As Lacan was trying to formulate a general theory of psychoanalysis, he borrowed ideas from the theory of Strauss and the models of linguistics. Besides that, he integrated the psychoanalytical approach in theorizing the concept of the unconscious in the light of structuralist analysis. He was of opinion that the way language is found to be structured, the unconscious could also be studied in that same way (Rendtorff, 2014). Lacan took help from the de Saussure's theory of linguistics and the theory of structural anthropology while analyzing the meaning of unconscious. He made use of the perspectives like signifier and signified to explicate the development of symbolic ordering over the history and culture. He realized that it is the language that gives place to the symbolic representation of desire and the unconscious relations between human beings. Therefore, the concept of the unconscious is supposed to be structured like language following the laws of structuralist linguistics (Rendtorff, 2014). According to him, the program of analysis related to structuralist and linguistics could be explained as psychological fantasies in the orderings of symbol and imaginary. Psychoanalysis was referred by him to be the science of structural laws that guide the significance of unconscious. So, what is more, important in psychoanalysis is that there should be a linguistic analysis of the signifier and signified in terms of their structures, as well as of the unconscious which could be manifested in the form of language.

III. Structuralism in human geography

Apart from the mentioned domains in the previous section, there are several other realms of social sciences and humanities that have widely used the essence of structuralism in their respective lines of discourse. Geography was no exception to this. The way geography was earlier influenced by the positivistic and humanistic approaches, most likely in the same way it was influenced by the domains of social sciences that were either the sources of structuralist analysis or somehow were influenced by the approaches of structuralism earlier than geography. However, the reflection of structuralism in human geography is found to be conspicuous even earlier to 1970s when the main impact of structuralist approach is most likely acknowledged. Peter Kropotkin and Elisée Reclus (Breitbart, 1981, Dunbar, 1981) the early anarchists, were found to be the practicing geographers. Gregory (1978) briefly recorded the work of Strauss while correlating that with human geography, although his work is not recognized to be a complete one in that regard. Actually, there have been limited contributions of the ‘structure as construct’ school and its scholars in relating structuralist approach with human geography and Gregory was not an exception in that case. However, an exception was the contribution of Jean Piaget (1896-1980) who belonged to the ‘structure as construct’ school but influenced the geographical research remarkably with a structuralist approach. His focus was on the acquisition of intelligence as the process of structural transformation. He argued that the development of a child’s intelligence about the space and geometry is subject to time and phases that vary qualitatively from one another. In each phase of development, new material is integrated with the previously held concepts. Such materials are consolidated and coordinated in such a way that it develops a self-regulating structure in which all materials are fitted in an organized way, not in a random form. His idea was later on criticized by Gould (1973) who stated that in spite of being the pioneer in working on the child’s psychological development process, Piaget was more concerned about the space and geometry, not much talked about the geographic image that a child retains while learning the things related to it. Later on, several other scholars also worked on the psychological developmental process of children, but all such studies attempted in revealing what people know and how that is being acquired by a particular process, rather than relating such investigations with the principles and arguments of structuralism. It could be because of the reason that there may remain a deeper structure of human consciousness which is very much relevant to the geographic research but was not studied during those days.

The most prominent entry of structuralist approach in the geographical researches could be evident through the works of Marxist geographers during 1970s when they strongly challenged the spatial science, sometimes represented in the form of cartography. According to Peet (1977), the growing interest in the geographers to adopt Marxist perspectives was because of the then western society’s dissatisfaction to the existing structure and increasing frustration with the positivist approach that repeatedly failed to achieve the acceptable solution and changes related to the social problems. In this context, David Harvey’s work ‘Social justice and the city’ (2010) acted as the stimuli for geographers to adopt the Marxist approach for the geographical research, because this approach is holistic and stressing more on the interdependence of the both economic and social issues in terms of production, consumption, and distribution. However, such borrowing of Marxist perspectives in geography was also debated in several grounds – from the adoption of the philosophy to the way it got applied in geography. A considerable number of geographers adopted the Marxist approach in presenting the manifold economic aspects of the capitalist societies but did not consider the fullest form of Marxism to correlate the production system with the further consumption and distribution system which means they failed to connect the economic aspects with the social issues (Smith, 1977). Sometimes, it has been criticized as an approach which was called as Marxian rather than Marxist (Asheim, 1979).

The actual form of structuralist geography indeed acknowledges the importance of the production system and its organization that significantly influence the creation and the structuring of social processes at all levels of the society. So, naturally, it deals with all the dialectic relationships that exist between the social processes on one hand and the natural environmental and spatial relationships on the other hand (Peet and Lyons, 1981). Very significantly, no particular streamline was framed to channelize the Marxist geographers in initiating the revolution, unless the consensus of the critical theory scholars suggested that the appreciation of real facts in the light of Marxist analysis can only increase the power and self-reflection leading to the ultimate emancipation from all forms of dominance. Therefore, the Marxist geography develops a theoretical as well as a political base that talks on behalf of the common mass of the ordinary people to challenge the forms of destruction and exploitation by the international ruling class people (Peet and Lyons, 1981). So, Marxist geography basically calls for a holistic perspective to deal with the structure of the reality. Some scholars like Dunford (1980) suggested, although there is a need of retaining a holistic perspective, the individual branches of social sciences do have the proper justifications to appear as separate disciplines because they have their distinctive foci of attention. From this particular perspective, human geography has the scopes to set up its distinct line of discourse that could be defined as the – study of the structure and spatial forms that have been produced historically and specified by the mode(s) of the production system. Such arguments brought the human geographers to a consensus that geography should come up with its own nature of perspective which would be self-reflecting and powerful in revealing the structures and spatial forms of the social issues. It paved the development of structuralist geography in due course of time.

Structuralist geography appeared to be comprised of the critiques just like the humanistic geographers who were trained to criticize the insufficiency of the other approaches in interpreting the outcomes of the social processes. Structuralist geographers mainly criticize the approaches believing that individual decision-making cannot reveal the real structural process that underpins the creation and recreation of geography. The impact of structuralist geography is more dominant in some areas of human geography.

One of such areas is the economic geography where the major focus of structuralist works was found to be the geography of development as well as underdevelopment. Structuralist analysis of such phenomena transformed the unilinear economic growth with deterministic spatial spread to the Marxist political economy. The writings of various scholars like Brookfield, Brewer, N. Smith stimulated much in this context.

The contribution of structuralist approach is also prominent in social geography, especially the social urban geography that influenced a lot in transforming the orientation of geographical research. In pre-structuralist perspective, geographers used to focus on the issues like who lives where in urban areas and also used to assume that there was a given set of social relations not changing over time, a mutual consensus about the rightness of such relations on the basis of which people would be allocated with a specific housing location and would be allowed to change their positions, and a free competition among the people to choose housing locations wherever they want. The structuralist perspective strongly challenged such assumptions by arguing that society is ever-changing and the relations are supposed to change accordingly. Such relations are altered rather by dissensus and sometimes even by conflict (Johnston, 1980). So, there remain several complex mechanisms that limit the free choice to select housing locations in the urban area. The contribution of David Harvey in this context is found notable.

Brian Berry (1969) termed political geography as 'moribund backwater' during the pre-structuralist period. The combination of idealist and positivist approach during the quantitative revolution in the 1950s and 1960s could not contribute much to political geography. Despite the electoral geography achieved more importance with positivist perspective (Taylor and Johnston, 2014), the actual revival appeared after the application of structuralist approach in its research orientation. Clark and Dear (1981) did the major contribution in political geography by integrating the theoretical issues related to the nature of state within the capitalist and many other modes of the production system. In the pre-structuralist time, such issues had not been considered to be studied under the domain of political geography.

In the historical geography, structuralist perspective provided a real method to study and interpret the pattern of the past. Besides that, if anybody is not interested into a specific pattern of the past, rather more interested in finding out the pattern of changes in several series of specific incidents of past, the structuralist approach is best suited in unfolding that as well. The contribution of Pred (1979) is notable in historical geography as he used the concept of structuration in his analysis.

Finally, it is noteworthy that the engagement of human geographers with structuralism was short-lived and worked as a transition when geographers took over some other approaches and dealt in more depth. "The move towards structuralism, never complete in geographical thought, represented a search for greater theoretical coherence and rigor (Peet, 1998, p. 112)." Structuralism ultimately did not give a satisfactory solution to find out the problems of empiricism, rather it took several forms of Marxism (like the structural Marxism) to provide a structural analytics of power and social processes (Gregory et al., 2011).

ePathshala पाठशाला
A Gateway to all Post Graduate Courses

MHRD
Govt. of India
An MHRD Project under its National Mission on Education through ICT (NME-ICT)

22nd December 2017

CERTIFICATE FOR CONTENT WRITER

This is to certify that **Subhajit Das**, Assistant Professor, Presidency University, Kolkata has participated in Content Writing of module for Paper ***Geographical Thought*** for **e-PG Pathshala – A Gateway to all Post Graduate Courses**, An MHRD Project under its National Mission on Education through ICT (NME-ICT).

(1) Structuralism

Dr. Taruna Bansal
Paper Coordinator

Prof. Masood Ahsan Siddiqui
Principal Investigator,
ePG pathshala (Geography)

Prof. Masood A. Siddiqui
Department of Geography
Jamia Millia Islamia
New Delhi-110025