Journal of the Nigerian Association of Mathematical Physics
Volume 31, (July, *2015*), pp 147 – 160
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Thermodynamic Properties Prediction of the Bulk Modulus Of Sediment-Hosted Disseminated Gold Deposits

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Abstract

An equation of state that connects pressure, volume, and temperature are very important in studying the temperature dependence of the thermal bulk modulus. Pressure, and temperature also determines the state of matter at different depths, different geological environments. A lot of work has been carried out on gold which includes: the determination of the Critical point of gold, geochemistry of gold, the role of organic matter and source of gold in sediment-hosted disseminated gold mineralization using Rock-Eva Analysis. Temperature effects on the universal equation of state of solids among others. Hence, this work aimed at the investigation of high temperature thermodynamic properties prediction of the bulk modulus of sediment-hosted disseminated gold using model with experimental data. Analysis was carried out with pressure vessel, analysis of both pressure and temperature effects on bulk modulus of gold can be use to predict the future state of gold deposits.

Keywords: Thermal analyses, high pressure, high temperature, compressed volume, disseminated gold.

1.0 Introduction

The knowledge of bulk modulus is very important in studying the physical state of mineral ore deposits; this can be used as a base line to predict the future state of other ore mineralization. A substance that is difficult to compress has a large bulk modulus but a small compressibility. A substance that is easy to compress has a high compressibility but a low bulk modulus. The more resistance a solid is to compression, the more pressure it takes to change the volume and the larger the bulk modulus. The bulk modulus of solid materials can be quite large, it is important for the fact that it tells how easy it is for a pressure wave to move through the solid. Since sound is essentially a pressure wave (alternating higher and lower pressure) K will be important in how well sound is transmitted through different materials

The high pressure and high temperature relationship cannot be overemphasized as regards to this study. The aim of this study is to investigate thermal bulk modulus relationship with high temperature and examine the impact on the compression of volume of SHDG deposits. Gold occur in two deposits: the Lode deposits which remain locked within their original solid rock formations e.g. Epithermal Au deposit [1, 2] consisting concentrations of Au (± Ag and base metals). The deposits are commonly young, generally Tertiary or Quaternary. They may be of similar age as their host rocks when these are volcanic in origin, or (typically) younger than their host. Nearly any rock type, even metamorphic rocks, may host epithermal Au deposits, although volcanic, volcaniclastic, and sedimentary rocks tend to be more common, and the Placer deposits which represent concentrations of loose particles of gold metal which are freed from their enclosing lode deposits by erosion, disintegration or decomposition of the enclosing rock, and subsequent concentration by gravity. Geological factors that influence potential environmental effects: deposit size- small size (100,000 metric tones) to large (200,000,000 metric tones) grade range from 1 to 20mg Au/t. [3]. This work centered on SHDG deposits. The samples were taken to the laboratory for analysis. These deposits exhibit a characteristic suite of trace elements, including Ba, Rb, Ce, Zr. , Cr, V, Zn, Cu, and major elements : SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, H_2O^+ [4].

The host rocks Amphibolites complex which may be grouped into migmatised gneiss complex and meta-sedimentary assemblages are the dominant host rocks for this deposit type. The deposits may also be hosted by intrusive suite of granitic rocks.

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1.1 Potential Environmental Considerations

Relative to other mineral deposit types, sediment-hosted gold deposits have relatively low potential for associated environmental concerns, especially in light of their large size. Natural ground water associated with some deposits can have elevated concentrations of Fe, Mn, As, Sb, Tl, Hg, Se, W, ± base metals. The temperature of ground water produced from some deposits is higher than ambient temperatures, which increases its metal transport capability. In comparison to other deposit types, potential downstream and offsite environmental effects are of relatively limited magnitude and spatial extent; however, surface and groundwater may include elevated concentrations of one or more of the elements As, Sb, Tl, Hg, Se, W, ± base metals.

1.2 Geology of Gold Deposits

Gold is actually a relatively scarce element on the crust of the earth, but it occurs in trace quantities spread throughout many different kinds of rocks and in many different geological environments. Although scarce, gold is concentrated by various natural geologic processes to form commercial deposits of two principal types' mentioned above; hard rock lode (primary) deposits and placer (secondary) deposits. The Lode deposits are the targets for the "hardrock" prospector seeking gold at the site of its deposition which was formed from mineralizing solutions within the earth. These deposits within solid rock are also the source of most of the new gold being mined today.

The deposits in Itagunmodi may be thought to originate from mountain-building process, sedimentary and volcanic rocks which may be deeply buried under the edge of the continent, where they are subjected to high temperatures and pressures resulting in chemical reactions that change the rocks to new mineral assemblages (metamorphism). This suggests that water is expelled from the minerals as they change and the water then migrate in upward direction, precipitating ore materials as pressures and temperatures decrease. The ore metals are thought to originate from the rocks undergoing active metamorphism deep within the earth.

Studies of rock structures, such as folds, faults, fractures, and joints, and of the effects of heat and pressure on rocks suggest why and where fractures occurred and where veins or other deposits might be found. At times, geologists will take an extensive number of soil and rock samples on a regular grid covering an area suspected to contain valuable deposits. Anomalous amounts of gold or elements known to be associated with gold in valuable deposits such as arsenic or Mercury will indicate areas which may require further study or even drilling. Studies of weathering processes and transportation of rock debris by water enable geologists to predict the most likely places for placer deposits to form. The occurrence of gold is not random or capricious; its presence in various rocks and its occurrence under differing environmental conditions follow natural laws.

2.0 Materials and Methodology

The study area is Itagunmodi, southwest, Nigeria. The sediment-hosted disseminated gold deposits (SHDGD) in Itagunmodi, Nigeria arelocated in the clayey soil types derived from variably migmatised gneiss, biotite-and-biotite hornblende-gneiss and weathered amphibolites respectively. Itagunmodi is located on latitude (DMS) $7^0 31'60''$ longitude (DMS) $4^0 39'0''$ and altitude (meters) 347 the time zone is east (est). The approximate population for 7km radius from this point is 12655 the analyses were carried out on 30 gold samples from randomly selected locations in Itagunmodi Southwest Nigeria. The samples were collected at various depths ranges between 5.50 m – 12.50 m. The sites was divided into five zones, A-E, six samples were taken from each location. Thereafter, (SHDG) samples were taken to the laboratory for analysis.

The site was divided into five zones labeled A-E; six samples were taken from each zone for analyses. The labeled were as follows:

Zones: A samples 1-6, B samples 2-12, C samples 13-18, D samples 19-24, E samples 25-30.

The geological map of the site showing the locations is shown in figure 1.

Figure 1: Geological map of the study area with the sampling location A-E

2.1 Experiment

Gold samples were placed in a improved high- pressure vessel, which is part of a fast capacitor –discharged circuit and in which a static pressure above 600Mpa can be reached with distilled water and pressure transmitting medium. The voltage drops across it and the temperature were recorded as a function of time. The initial volume (V_0), and the room temperature (T_0) and the initial pressure (P_0) were noted. As the temperature increased with time, the subsequent values of pressure, temperature and volume were recorded. The samples were run three rounds. During the heating period, the current through the samples, voltage across the samples, were measured as function of time. Since the main emphasis of this work was to predicts the thermal bulk modulus relationship with temperatures. Hence, the effects of high pressure and high temperature on the volume of the samples as functions of the surrounding pressure which were measured with pressure gauge, the gauge on the pressure vessel was 150 percent of the maximum operating pressure. This allows the gauge to operate in the most accurate pressure range and prevents the gauge from being stressed to its full range, effecting the calibration, and the temperatures were measured from the thermocouple or thermowell which is within the vessel. The volumes were measured with graduated attached cylindrical flask. The data were analyzed using the applicable equation of state.

2.2 Theoretical Background

Consider the equation of state connecting P, V, and T. If the increase in internal pressure ΔP_{Th} caused by heating a solid at constant temperature (thermal pressure) is given by;

$$\left(\frac{\partial P}{\partial T}\right)_V = \alpha K_T = \gamma_{th}\frac{C_V}{V} \qquad \text{----------- (1)}$$

Integration of (1) at constant volume also yields:

$$\Delta P_{Th} = \int_{T_1}^{T_2} \alpha K_T dT \qquad \text{------------ (2)}$$

It is experimentally verified in many solids that αK_T are approximately independent of temperature [5]. Equation (2) can be then be written:

$$\Delta P_{Th} = \alpha K_T dT \qquad \text{---------------- (3)}$$

Or:

$$\frac{\Delta P_{Th}}{K_T} = \frac{\Delta V}{V} = \alpha \Delta T \qquad \text{----------------- (4)}$$

$$\frac{\Delta V}{V} = \alpha (T - T_0) \qquad \text{------------------ (5)}$$

$$\frac{\Delta P_{Th}}{K_T} = \alpha \Delta T \qquad \text{------------------- (6)}$$

The volume strain is given the relation:

$$\Delta \eta = 1 - \frac{V}{V_0} \qquad \text{------------------ (7)}$$

Where Δ□ is the volume strain and where V_0 is the reference initial volume.

The thermal heat energy and electrical heat formulas can relate to determine the time prediction for the compressed volume of the Ore. The heat capacity is given as:

$$H = mc\theta \qquad \text{------------------ (8)}$$

$$= \rho CV \Delta T \qquad \text{------------------ (9)}$$

$$= \rho CV (T - T_0) \qquad \text{----------------- (10)}$$

Electrical energy can be expressed as shown:

$$IVt = mC\Delta T = mC(T - T_0) \qquad \text{---------------- (11)}$$

$$IVt = mC\Delta T = \rho CV(T - T_0) \qquad \text{------------- (12)}$$

$$t = \frac{\rho CV (T - T_0)}{IV} \qquad \text{----------------- (13)}$$

3.0 Results and Discussion

The results of the analysis conducted showed that as pressure and temperature increases, the volume of sediment-hosted gold reduces, meaning that the compression in volume of the (SHDG) deposits increases moderately. The model used was of the form: $\Delta P_{Th}=\alpha K_T(T-T_0)$ and $\Delta V/V_0=\alpha(T-T_0)$, where αK_T, α, represent the slope respectively. The average values of pressure, temperature and compressed volume ranged between (436.40-549.00) Mpa, (2327.30-2871.70) °C and (0.041-0.690)*10^{-3} m^3 kg^{-1}. The developed model was also applied to predict the thermodynamic variation of bulk modulus, the bulk modulus K_T ($V=V_0$) decreases with temperature for the analyzing values of $(\partial K_{T0}/\partial p)_T$ [i.e. $V=V_0$], the bulk modulus ranged between (0.68-9.76) Gpa for data samples. Figures (3-32) represent the plots of bulk modulus against temperature for all the analyses. The values tend towards zero with increased in temperature and time. This shows that the bulk modulus decreases at high temperature due to increase in strain Δ□.

The thermal data for the samples shows that K_T ($V=V_0$) decreases with temperature (T) for experimental values of $(\partial K_T/\partial P)$. The slope $\partial K_T/\partial T$ is -9.20881*10^{-4} for sample1 as a representation for the samples. It was also observed that the trend of bulk modulus when compared with the time shows that the bulk modulus decreases with increase in time (or temperature), it is an indication that a time will come when the disseminated gold will be very scarce or may not even be available. The volume compressed by about 0.008813*10^{-3} s^{-1} for every 0.150*10^{-3} *10^{-3} m^3.

Experimentally, all materials are compressible (i.e., K is finite). Physically, as the temperature is increased through the sediment hosted disseminated gold; the distance between the molecules is expected to increase [6]. The resulting decrease in the bulk modulus may be attributed to the consequent decrease in the slope of the inter-atomic potential, as SHDG is heated and softens, it becomes more compressible.

The effect is when the pressure exerted on a substance is increased, the volume the substance occupies decreases, which means the intermolecular distance decreases, solids have almost no intermolecular distance, a liquid have very small intermolecular distances and gases a large intermolecular distance. When the intermolecular distance decreases, the state of matter is lowered. (A solid is a lower state of matter than a liquid, and a liquid is a lower state of matter than a gas). Basically, when the pressure on a substance increases, the lower state of matter is stabilizing. Compressibility and melting point also increases with increase in pressure.

4.0 Conclusion

In conclusion, since all materials are compressible, the singularity is of no practical import. This interpretation is consistent with experiments cited above. The analysis shows that the rate at which the volume of the SHDG ore volume compressed means the high temperature thermodynamic properties indicated the decay in bulk modulus for every rise in temperature. In future, the sediment-gold may likely become scanty; leaching may take place that may lead to transportation of metals to various locations where new discovery may be found. The main reason for this can be predict from the formation of the sediment-hosted gold deposits.

5.0 Acknowledgement

The Authors acknowledge the contributions of Mr. N. Akhiheru of the Geology Department University of Ibadan, Ibadan. We also appreciate the various suggestions and contributions made by Professor A. A. Okunade and Dr. M.O. Awoyemi both of Physics Department Obafemi Awolowo University, Ile-Ife and Professor E.O. Oladiran of Physics Department University of Ibadan, Ibadan and also Mr. Niyi of Itagunmodi for his support to access the site and samples used for the research work. We thank you all.

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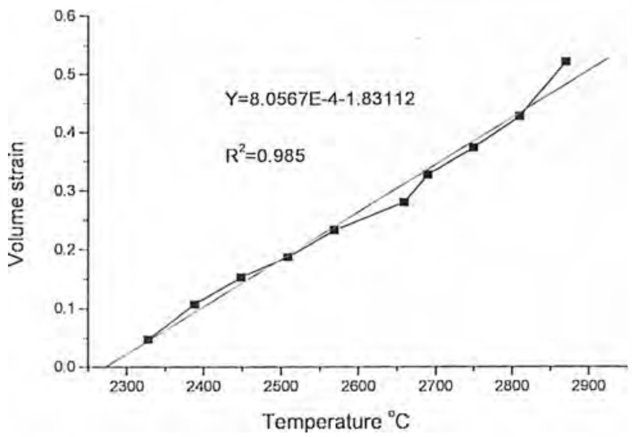


Figure 2: A representation of volume strain plotted against temperature (sample 1)

The above graph show that an increase in strain results in a lowering of αK_T at high value of temperature T.

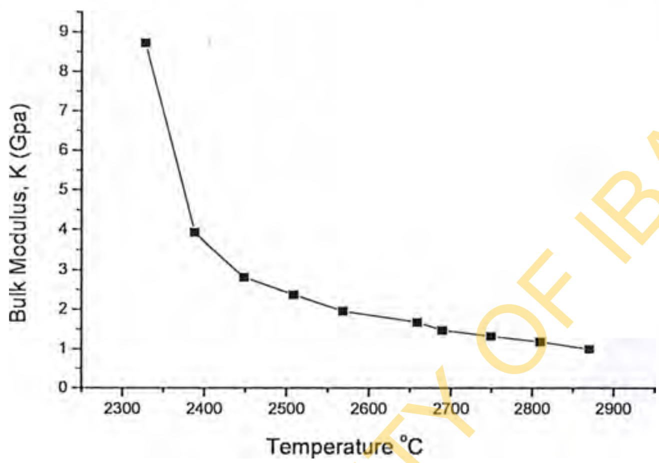


Figure 3: Bulk modulus against temperature (sample 1)

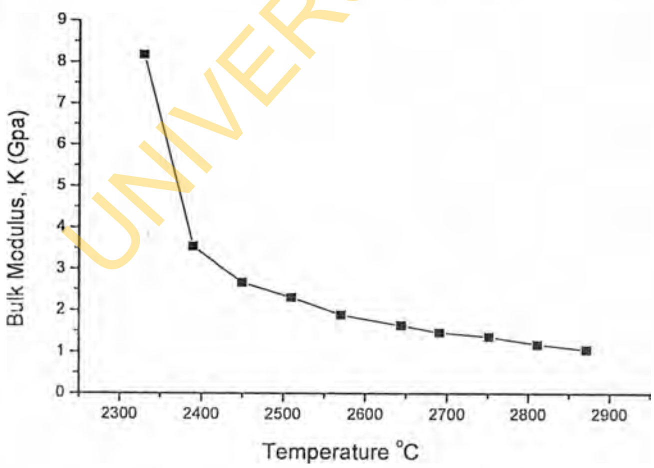


Figure 4: Bulk modulus against temperature (sample 2)

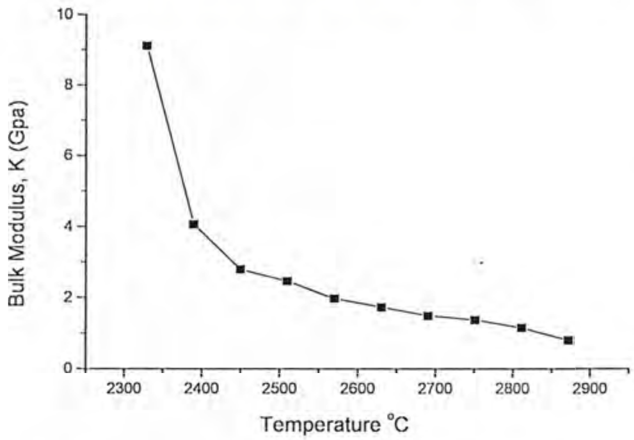


Figure 5: Bulk modulus against temperature (sample 3)

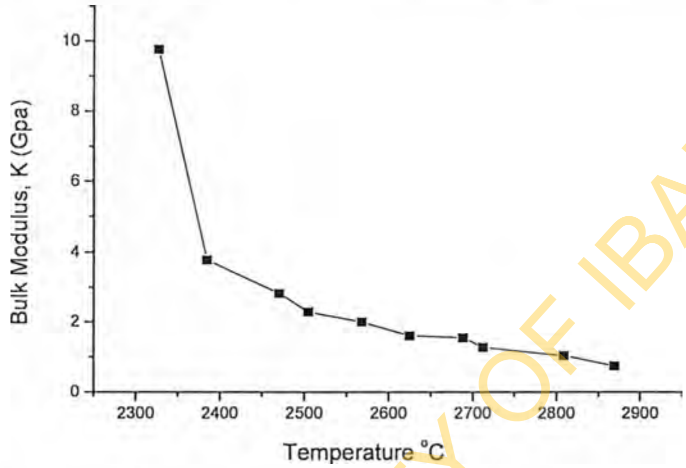


Figure 6: Bulk modulus against temperature (sample 4)

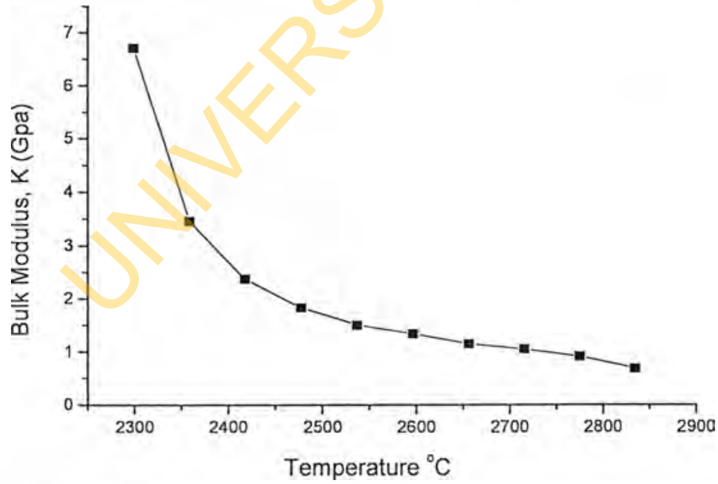


Figure 7: Bulk modulus against temperature (sample 5)

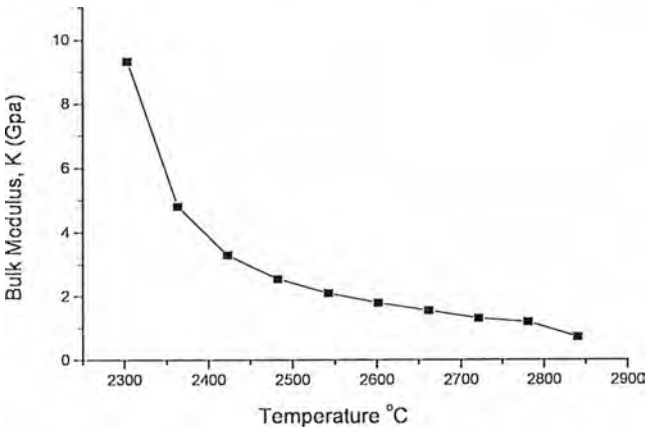


Figure 8: Bulk modulus against temperature (sample 6)

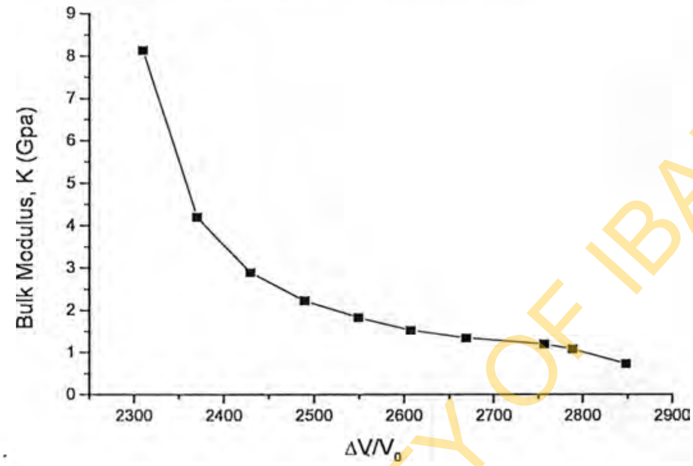


Figure 9: Bulk modulus against temperature (sample 7)

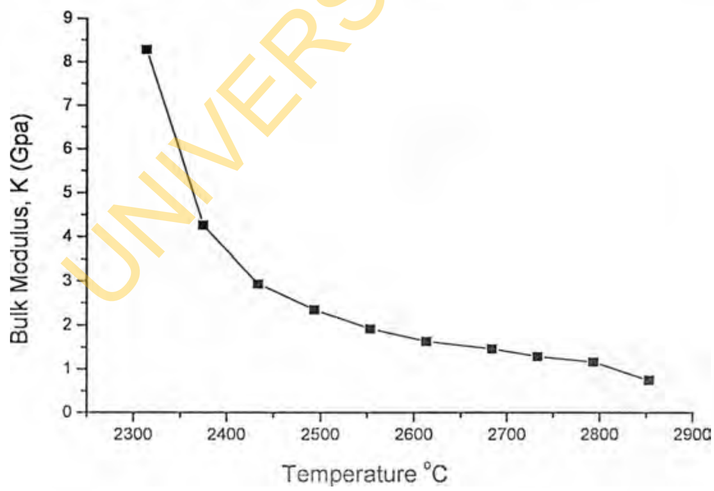


Figure 10: Bulk modulus against temperature (sample 8)

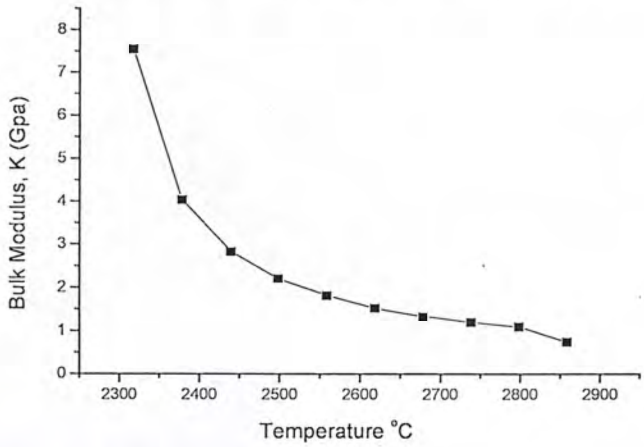
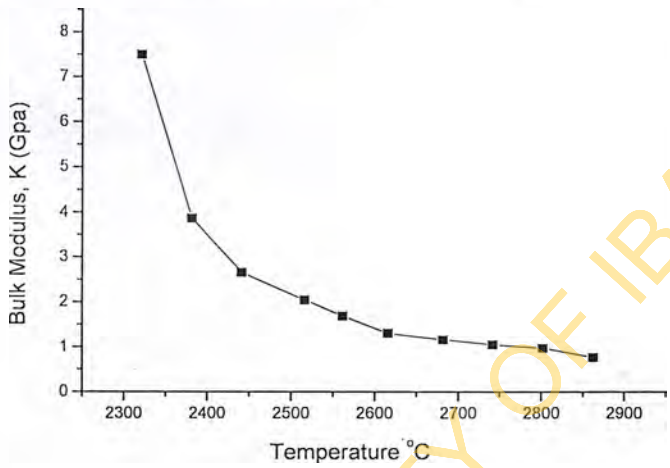


Figure 11: Bulk modulus against temperature (sample 9)



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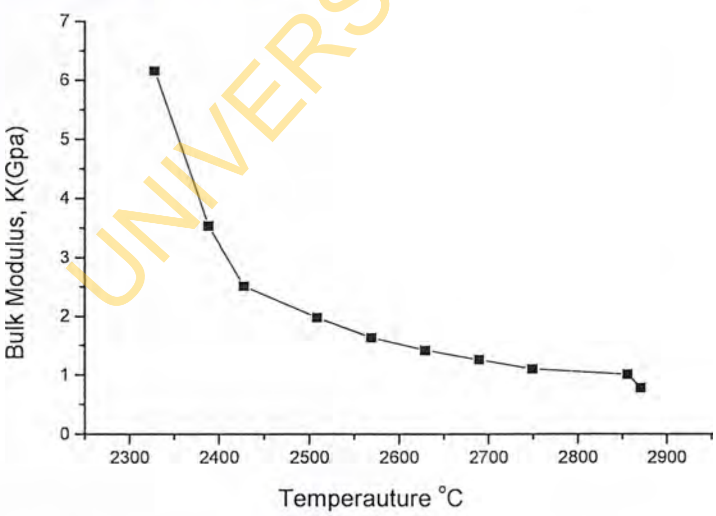

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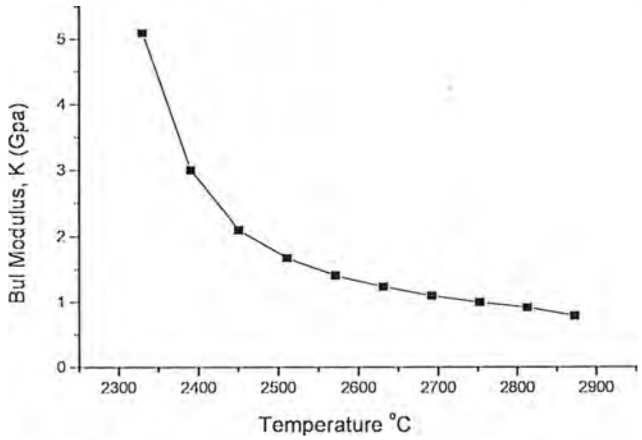

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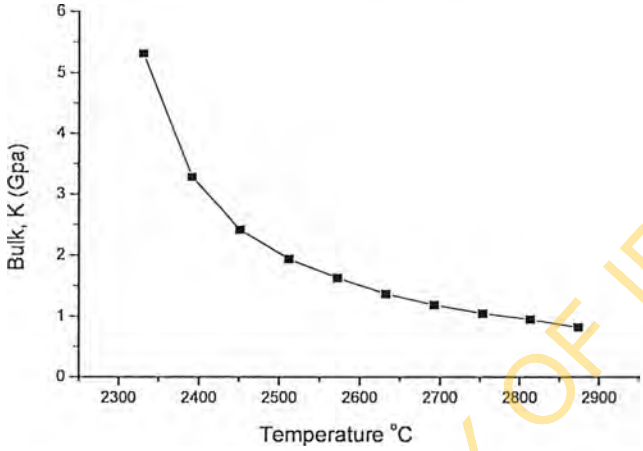

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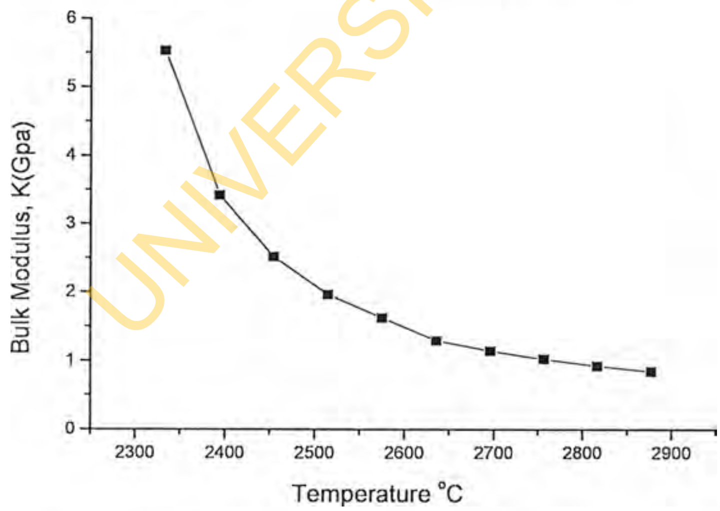
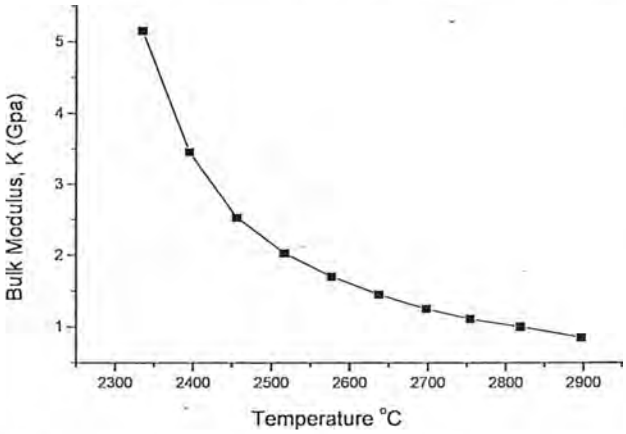


Figure 16: Bulk modulus against temperature (sample 14)



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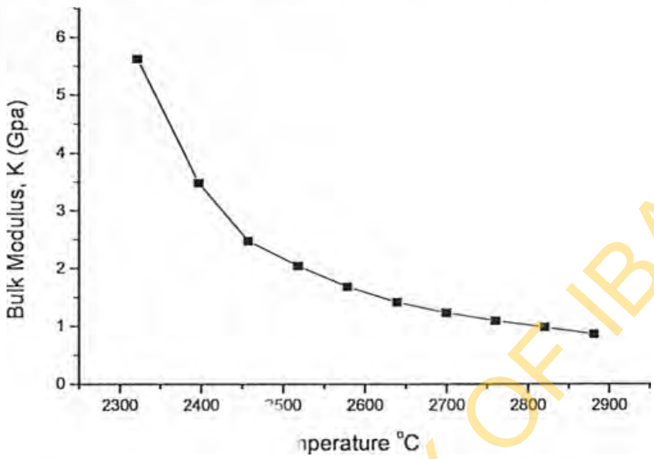

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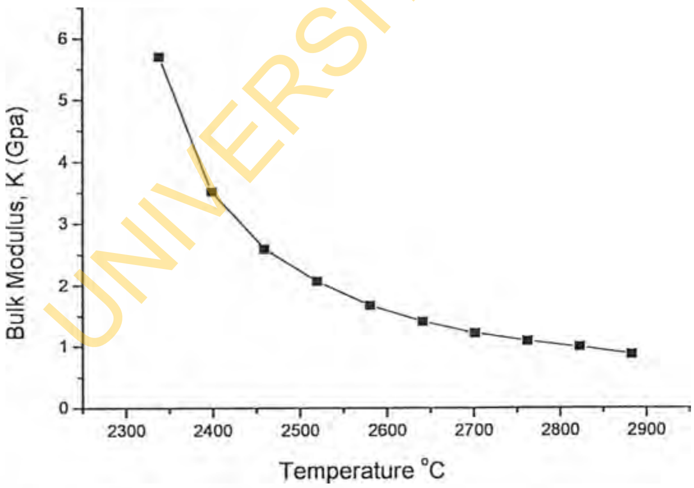

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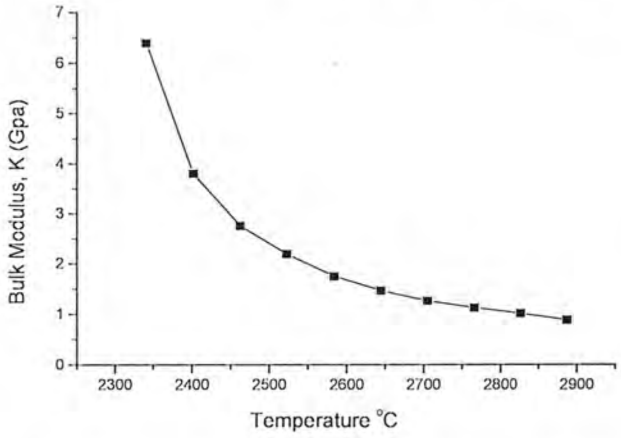

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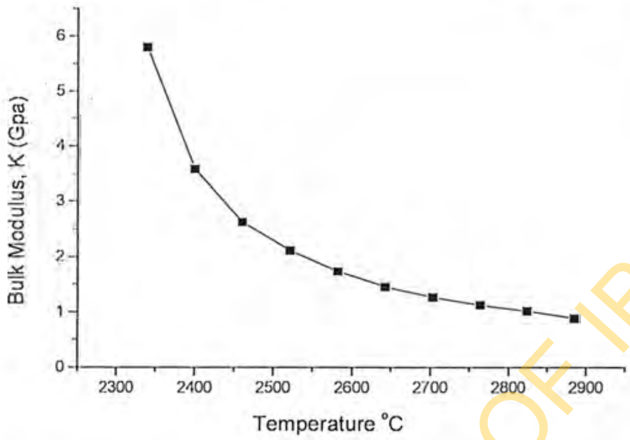

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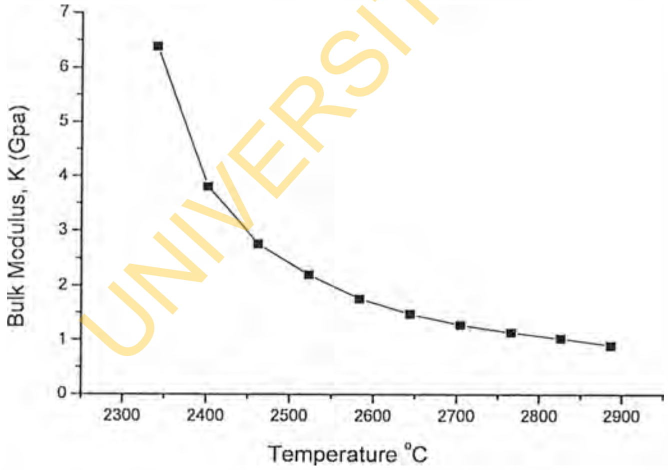

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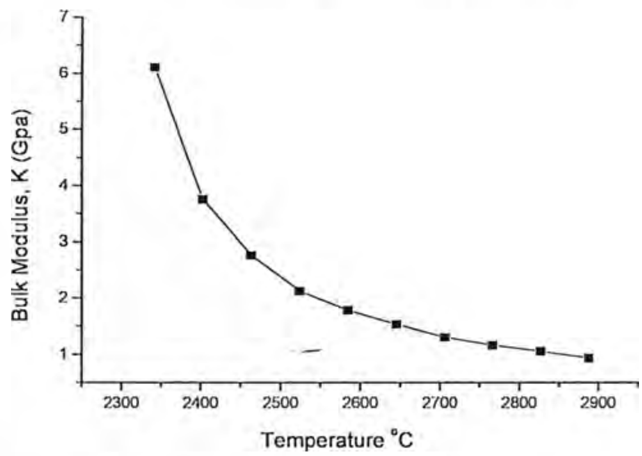

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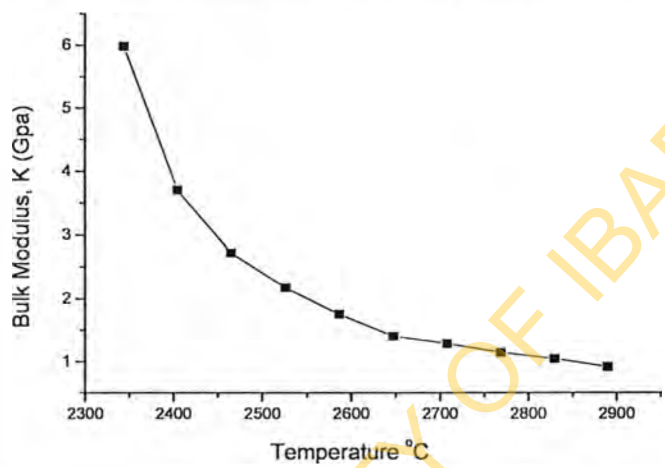

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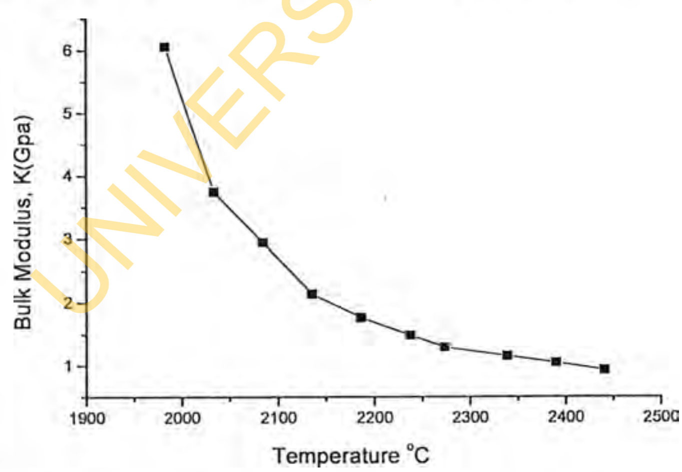

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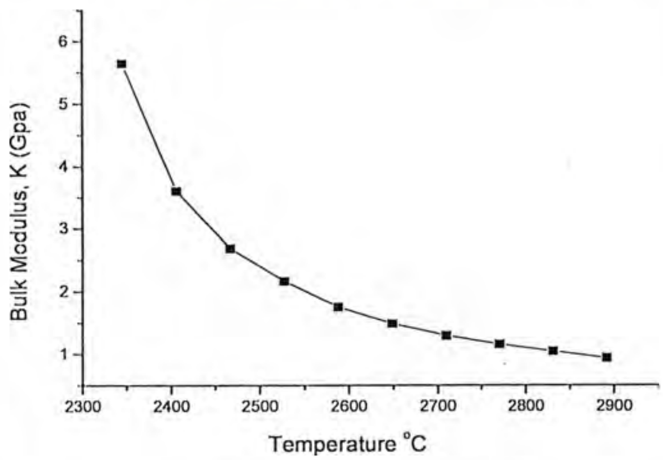

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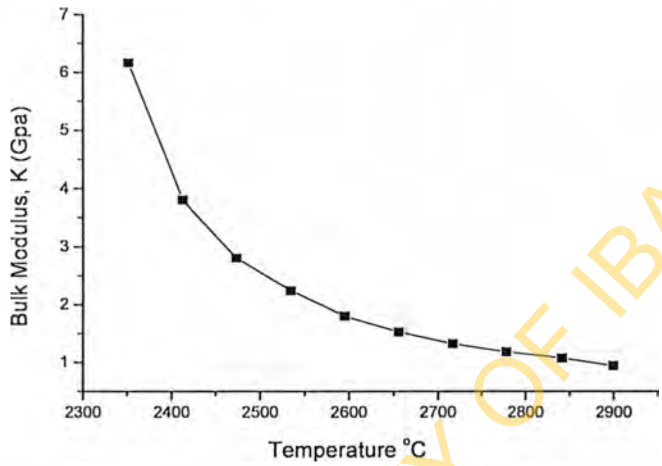

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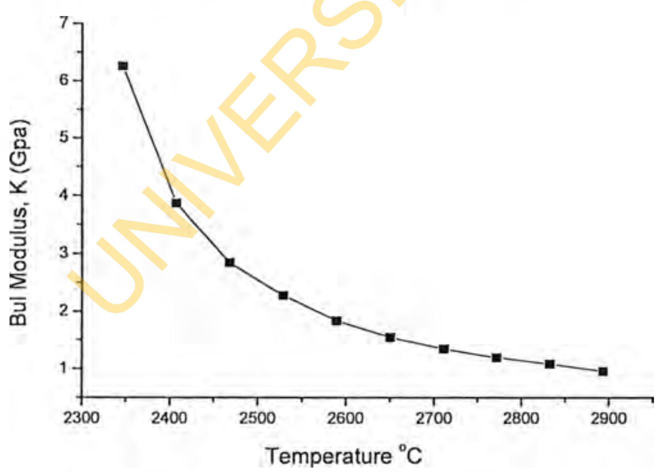

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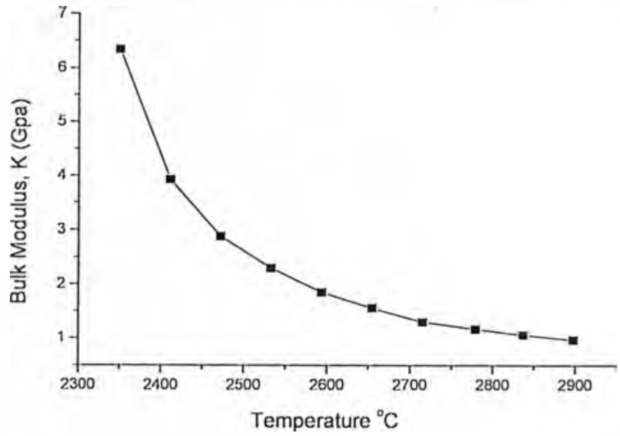

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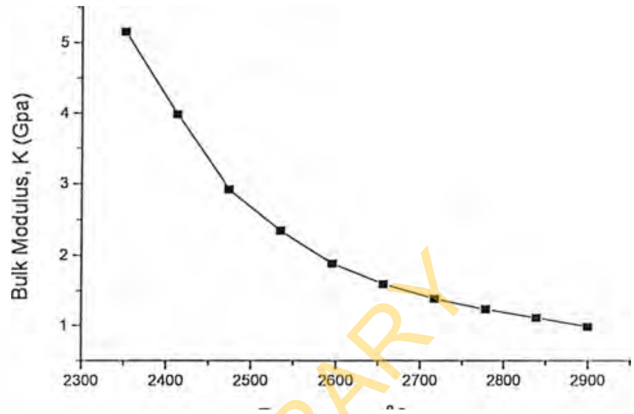

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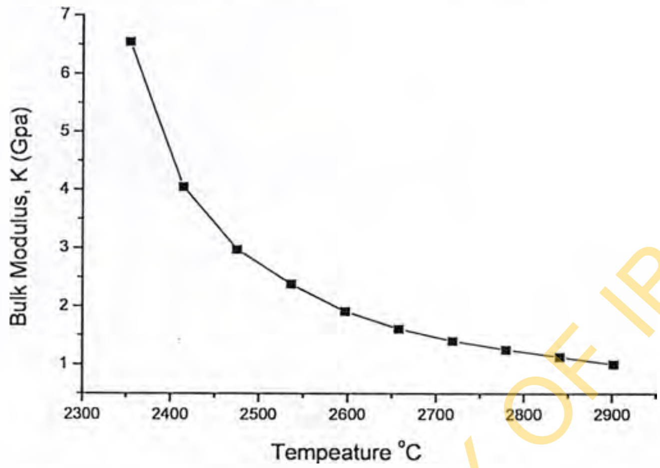

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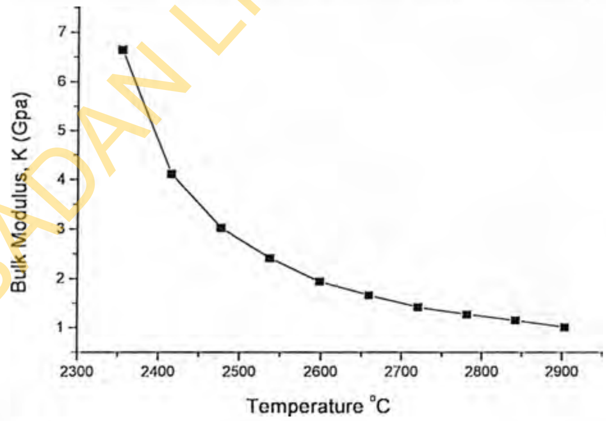

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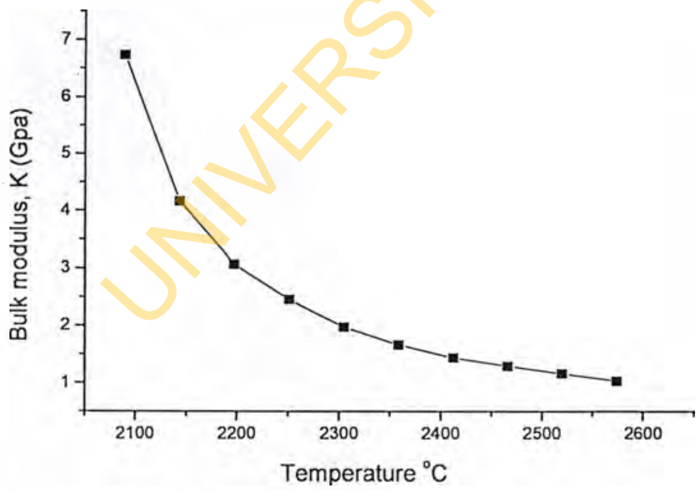

Figure 32: Bulk modulus against temperature (sample 30).