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Interpretation of thermoluminescence patterns around a Wyoming roll-type uranium deposit

by

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Contents

Illustrations

Interpretation of thermoluminescence patterns around a Wyoming roll-type uranium deposit

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Abstract

Thermoluminescence from quartz and feldspar grains in samples collected from the vicinity of a Wyoming roll-type uranium deposit show an increase in the importance of high-temperature thermoluminescence relative to low-temperature thermoluminescence of samples which are believed to be former positions of the migrating mineralized front. This effect is believed to be due to the increased radiation in the ore coupled with the faster rate of fading of low-temperature thermoluminescence compared to high-temperature thermoluminescence. Both the ratios of thermoluminescent responses from any of a variety of temperature ranges and glow curves (plots of intensity of thermoluminescence versus temperature) can be used to detect the increased importance of high-temperature thermoluminescence relative to low-temperature thermoluminescence of previously mineralized samples. Both ratios and glow curves present a systematic pattern around this deposit; these patterns may have application in uranium prospecting.

Introduction

It has long been known that thermoluminescence (the emission of light from a crystal on heating) of mineral samples is related to the radiation history of the sample. This knowledge inspired Sharp and others (1964), and Hayslip and Renault (1976) to apply thermoluminescence to uranium prospecting. Their efforts were thwarted however, by the inability to separate the variation in thermoluminescence related to differences in the radiation doses among the samples from the variation in thermoluminescence related to differences in other factors that affect thermoluminescence. In a

previous study, Spirakis, Goldhaber, and Reynolds (1977) concluded that the ratio of the thermoluminescent response in the temperature range of 100°C to 322°C to the thermoluminescent response in the temperature range of 315°C to 400°C was an effective means of subduing the effects of the variation in factors other than radiation dose on the thermoluminescence of the sample. When the ratioing technique was applied to samples of quartz and feldspar grains around a roll-type uranium deposit in south Texas, a systematic pattern of thermoluminescent ratios was observed. The purposes of this study are to test the technique of ratioing thermoluminescent responses on another roll-type deposit, to seek the optimum temperature ranges of thermoluminescence to be used in ratioing, and to determine if glow curves (plots of thermoluminescence versus temperature) reveal a systematic pattern around the ore.

Theory

The reader interested in a detailed discussion of thermoluminescence and the ratioing technique is referred to Spirakis, Goldhaber, and Reynolds, (1977) and the references included in that work. Very briefly, thermoluminescence arises from the escape of electrons trapped in crystal defects. As the electrons escape from their metastable positions in the crystal defects and return to more stable positions in the crystal lattice, they emit energy in the form of light. Heating the crystal increases the energy of the electrons and their escape rate increases. Free electrons which may become trapped in the defects are generated by ionizing radiation, as from radioactive decay, passing through the crystal. Thus, thermoluminescence is dependent on both the dose of radiation and the number of defect traps. Thermoluminescence observed at lower temperatures (about 100°C) arises from the escape of electrons from traps with a lesser escape energy than is typical

of the traps which emit electrons at high temperatures (as much as 400°C in this experiment). Even at ambient temperatures, electrons eventually escape from the traps; electrons in traps with a low-escape energy, escape faster than electrons in high-escape energy traps. Consequently, low-temperature thermoluminescence fades or decays faster than high-temperature thermoluminescence. Thus after a sample has received a dose of anomalous radiation as from the passage of a uranium-mineralized solution front, low-temperature thermoluminescence will fade to a background level, dependent on the local concentration of radioactive elements, faster than high-temperature thermoluminescence. The number of low-temperature traps is not necessarily the same as the number of high-temperature traps, but the factors that increase crystal defects (that is traps) such as strain and impurities, are likely to affect the number of both low- and high-temperature traps in the same manner. Thus a sample with a high number of traps is likely to display a high thermoluminescence in any temperature range. Once enough time since irradiation has passed to allow low-temperature thermoluminescence to approach a background level, the low-temperature thermoluminescence is dependent on the background radiation and the number of low-temperature traps; at the same time, high-temperature thermoluminescence is dependent on the background radiation plus the previous radiation and the number of high-temperature traps. Assuming that the number of high-temperature and low-temperature traps increases or decreases together, the ratio reduces the effects of the variation in the number of traps on the thermoluminescent response of the sample. Thus ratioing may reveal differences in thermoluminescence which otherwise would have been masked by the effects of the variation in the number of traps on thermoluminescence.

Methods

Samples used in this study were collected from the vicinity of a roll-type uranium deposit in the southern part of the Powder River Basin, Wyoming. Six samples (OS. 1, 2, 3, 7, 9, and 12) were from the oxidized tongue updip of the ore; these samples probably experienced anomalous irradiation from the migration of the mineralized front. Five mineralized samples (OS. 16, 21, 35, 42, and 47) and two samples from reduced ground (OS. 46 and 48), which probably never were ore grade, were also used in this study. All of the samples consisted of poorly consolidated sandstone which disaggregated easily with little grinding. The samples were sieved to a size range of 100 to 115 mesh (125 to 149 microns) and HCl was added to remove carbonates. Clays were washed out and the samples were dried at room temperature. Exposure to light, which may drain thermoluminescence, was avoided. A Harshaw 2000[1] thermoluminescence system was used to measure the thermoluminescence of two or three splits of each sample. (For a description of the instrument, see Renault and Hayslip, 1976.) The results were recorded as glow curves (plots of temperature versus the intensity of thermoluminescence) for temperatures as much as 400°C.

The temperature range from 160°C to 400°C was broken into 20°C increments and the thermoluminescence of each increment was calculated from the area under the glow curve. For the purpose of ratioing, low-temperature thermoluminescence was calculated by summing the thermoluminescence of the 20°C increments from 160°C to some selected temperature; high-temperature thermoluminescence was computed as the sum of the thermoluminescence of all the increments between that selected temperature and 400°C. For example, the

[1]Brand names are used for descriptive purposes only and do not necessarily imply endorsement by the U.S. Geological Survey.

thermoluminescence ratio at 240°C equals the sum of the thermoluminescence from 160°C to 240°C divided by the thermoluminescence from 240°C to 400°C.

Results and discussion

Ratios of the sum of the thermoluminescence below a certain temperature to the sum of the thermoluminescence above that same temperature for each sample are plotted according to the postions of the samples relative to each other in figures 1, 2, and 3. These plots include ratios from 180°C to 380°C. All of the samples which were irradiated by the passage of the uranium-mineralized front (OS. 1, 2, 3, 7, 9, and 12) display a lower ratio of low-temperature to high-temperature thermoluminescence than do the samples from the ore (OS. 16, 21, 35, 42, and 47) or from the reduced ground downdip of the mineralization (OS. 46 and 48). This difference in the ratios is present in all temperature ranges from 180°C to 380°C. Although the scale at which the data are plotted make the higher temperature ratios appear to be more useful in differentiating the samples affected by the migration of the ore than the samples not affected by the migration of the ore, the percent difference between the ratios at any one temperature is nearly the same in all temperatures and no clear optimum temperature is defined.

The pattern of ratios in this deposit is in close accord with the pattern observed around a south Texas roll-type deposit (Spirakis, Goldhaber, and Reynolds, 1977). Both deposits are characterized by lower ratios in the oxidized tongue and both studies suggest that the ratios increase slightly as the ore is approached from the oxidized side. The lower ratios in the oxidized tongue indicate an increase in the importance of high-temperature thermoluminescence relative to low-temperature thermoluminescence.

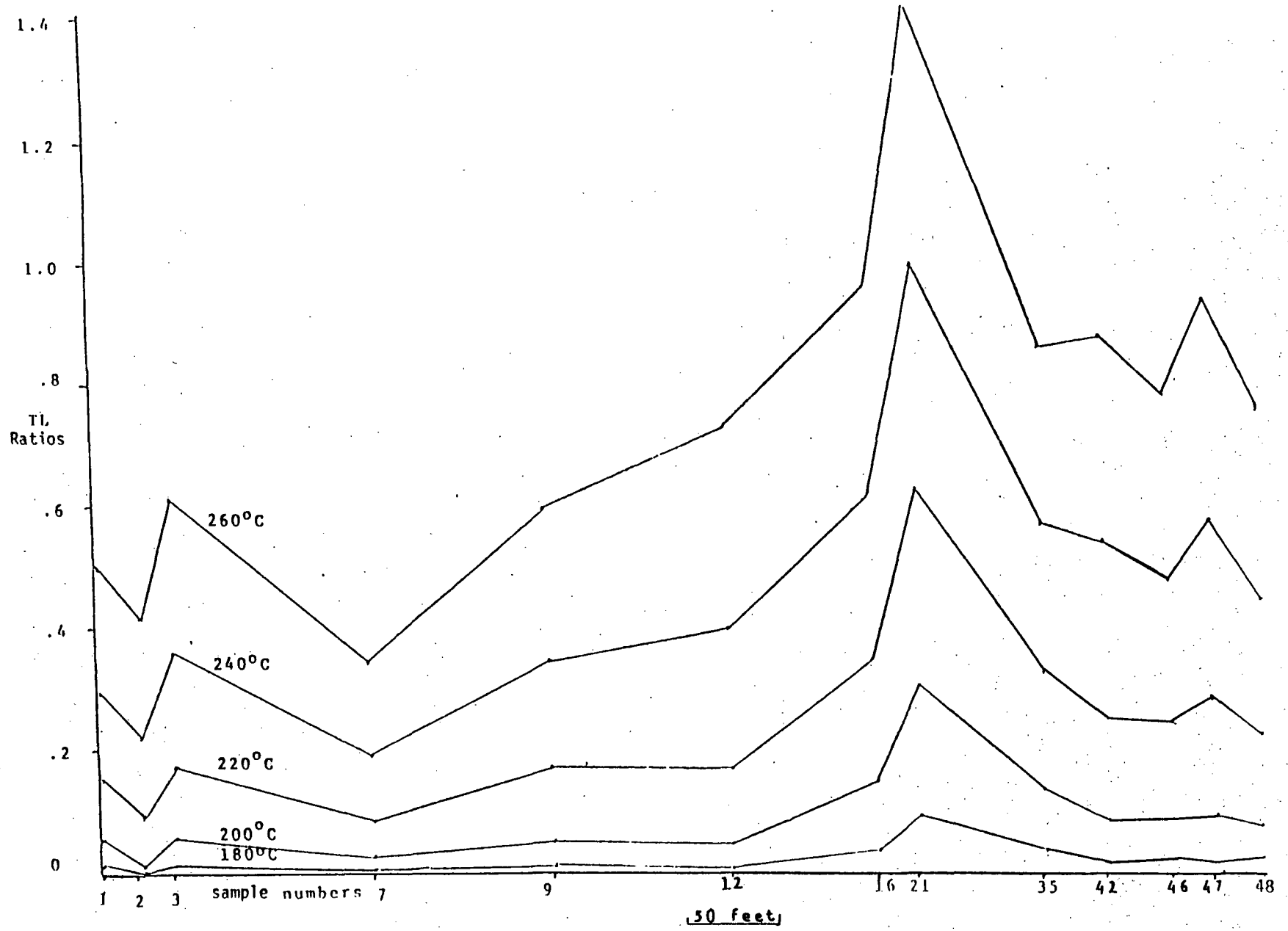

Figure 1.--Ratios of thermoluminescence (TL) below specified temperatures (180°, 200°, 220°, 240°, and 260°) to TL above the same temperatures plotted according to the relative positions of the samples from the Powder River Basin, Wyo.

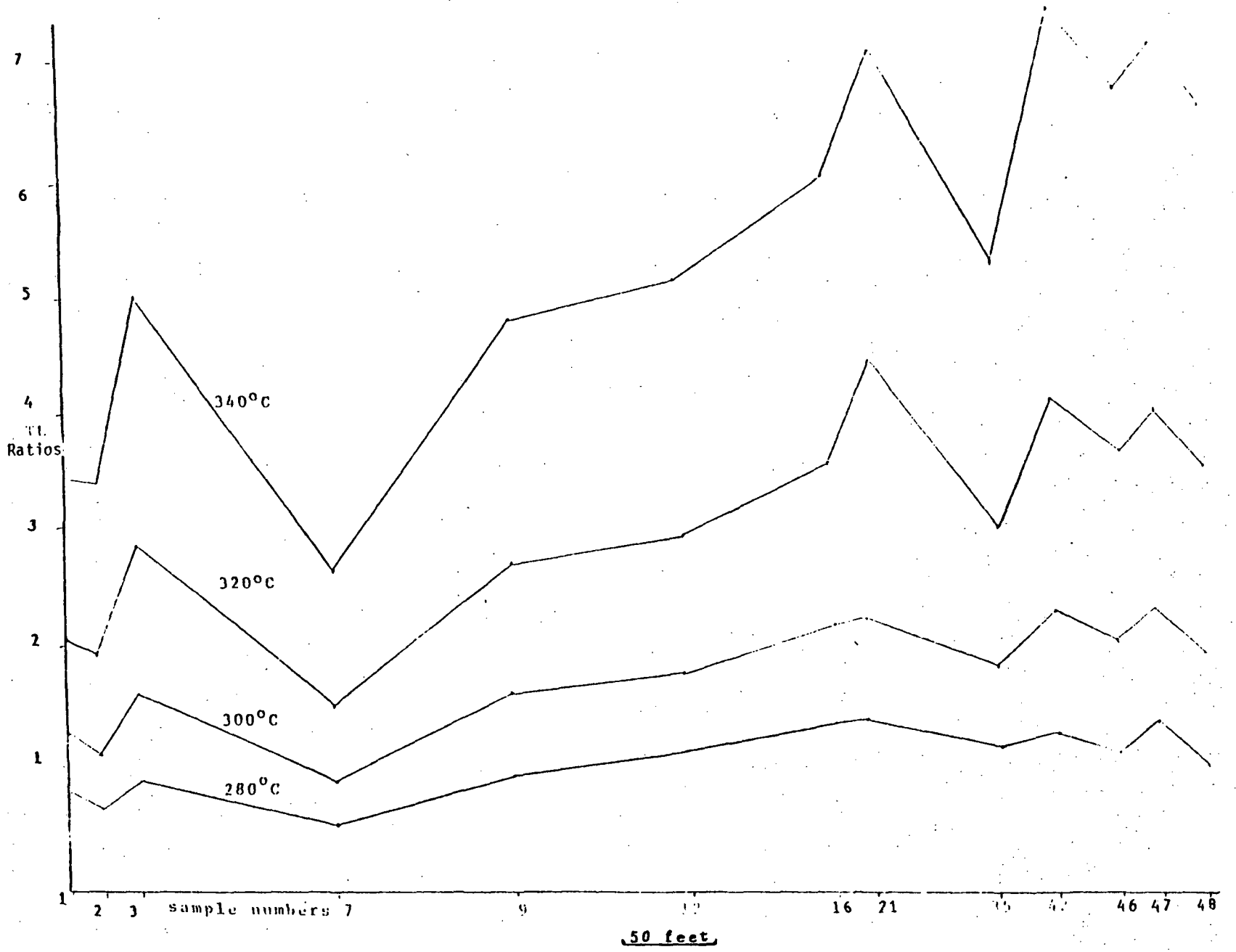

Figure 2.--Ratios of thermoluminescence (TL) below specified temperatures (280°, 300°, 320°, and 340°) to TL above the same temperatures plotted according to the relative positions of the samples from the Powder River Basin, Wyo.

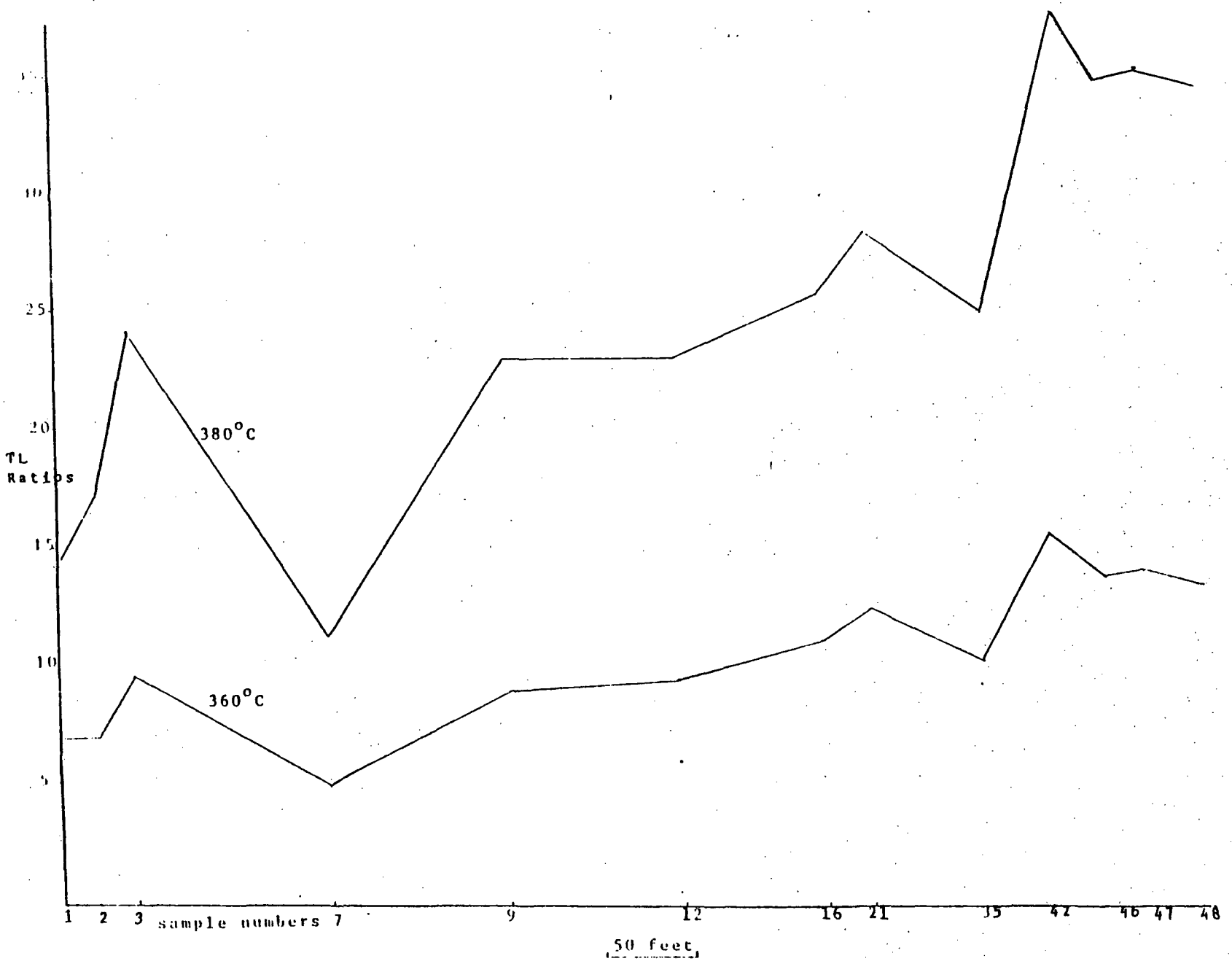

Figure 3.--Ratios of thermoluminescence (TL) below specified temperatures (360° and 380°) to TL above the same temperature plotted according to the relative positions of the samples from the Powder River Basin, Wyo..

Glow curves also show the increased importance of high-temperature thermoluminescence where the ore has passed. Figures 4-8 present a progression of glow curves across the deposit. Figure 4 is a combination of several glow curves from samples (OS. 1, 2, 3, and 7) on the oxidized side of the ore. Figures 5 and 6 are from samples which are progressively closer to the ore (OS. 9 and 12). Figure 7 is a composite of glow curves from several mineralized samples (OS. 16, 21, 35, 42, and 47), and figure 8 presents the glow curves from the two reduced samples downdip from the mineralization (OS. 46 and 48). A contrast between the glow curves of the unmineralized samples updip of the ore (fig. 4) and the unmineralized samples downdip of the ore (fig. 8) reveals the increase in the importance of high-temperature thermoluminescence relative to low-temperature thermoluminescence where the ore has passed. This difference is most apparent in the highest portion of temperature range. Within the mineralized samples, summarized on figure 7, a high intensity of thermoluminescence is observed in all temperature ranges; low-temperature thermoluminescence is particularly intense. Glow curves of those samples near the mineralization on the oxidized side (figs. 5 and 6) represent a transition from the mineralized samples (fig. 7) and the samples from the oxidized tongue (fig. 4). The position of sample 12 (fig. 6), adjacent to the ore, may account for the similarity of the glow curve of this sample and the glow curves of the mineralized samples (fig. 7). The position of the migrating roll was probably located at sample 12 more recently than the samples farther updip. Thus, sample 12 has had less time to equilibrate with its lower level of radiation than the samples farther updip. The glow curve of sample 9 (fig. 5) may represent a closer approach to equilibration with the lower levels of radiation after leaching of the ore than sample 12. Figure 5 shows an intensity of thermoluminescence greater than that of figure 4 but

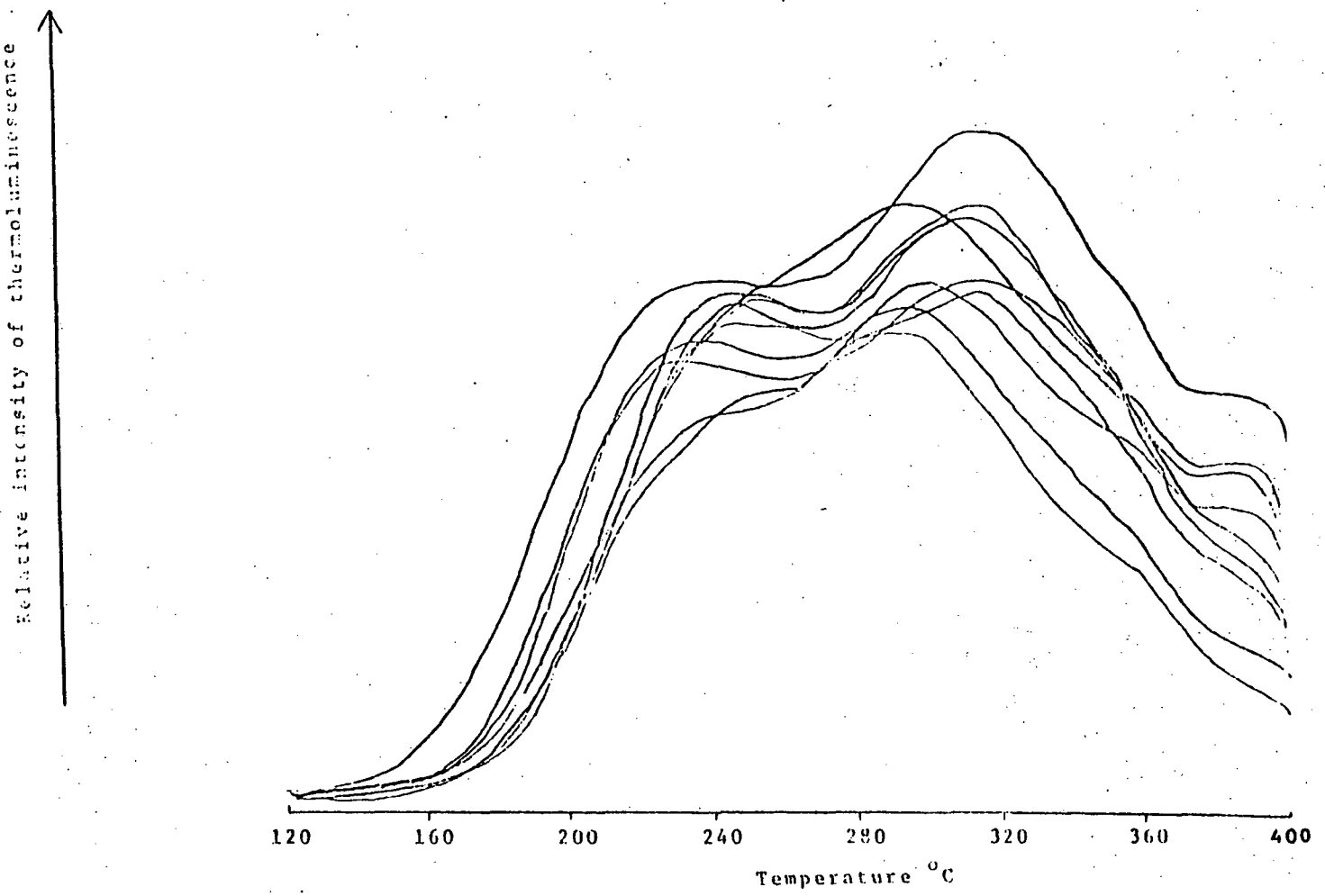

Figure 4.--Glow curves of samples 1, 2, 3, and 7, located updip of the ore in the Powder River Basin, Wyo.

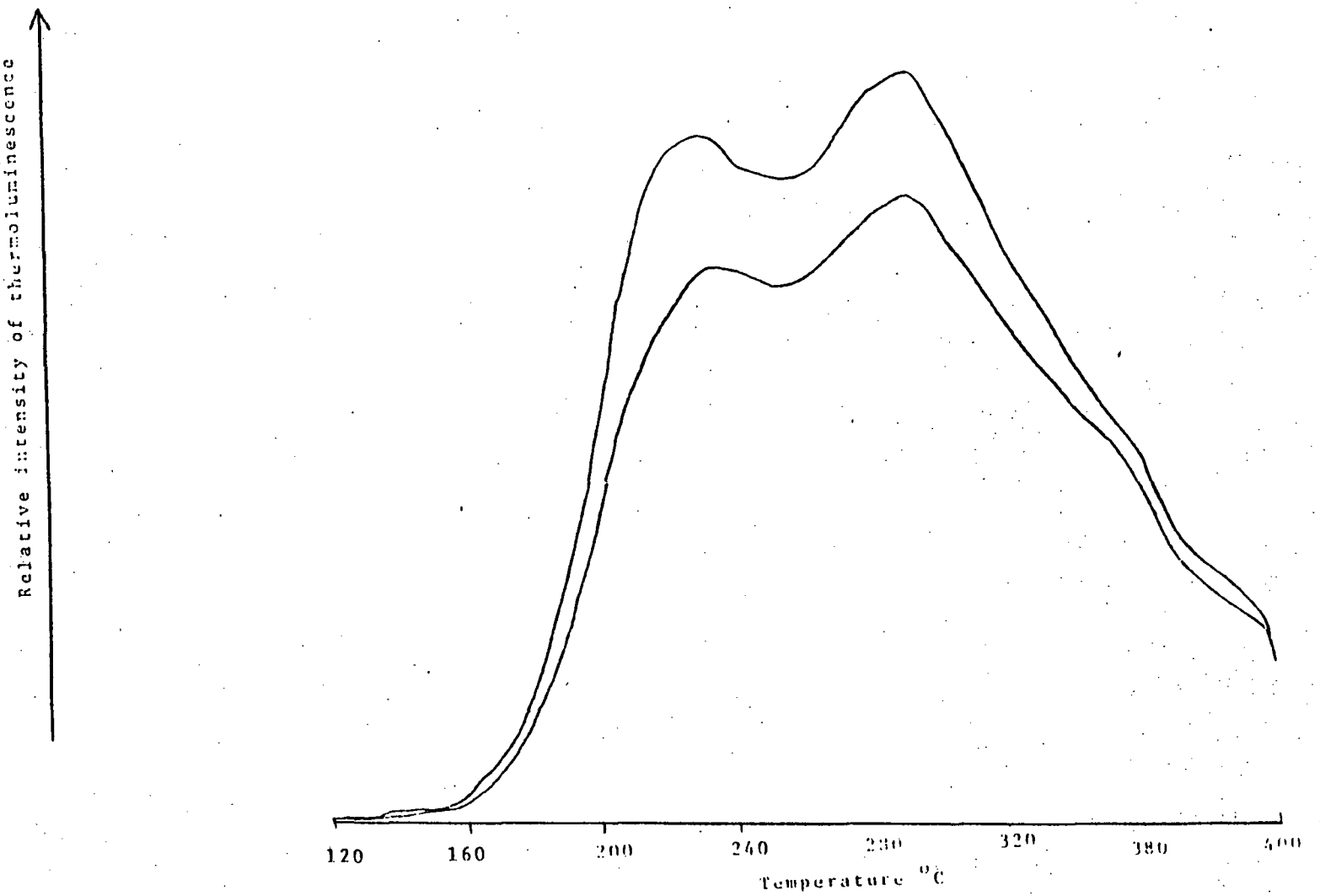

Figure 5.--Glow curves of sample 9, located near the ore on the updip side in the Powder River Basin, Wyo.

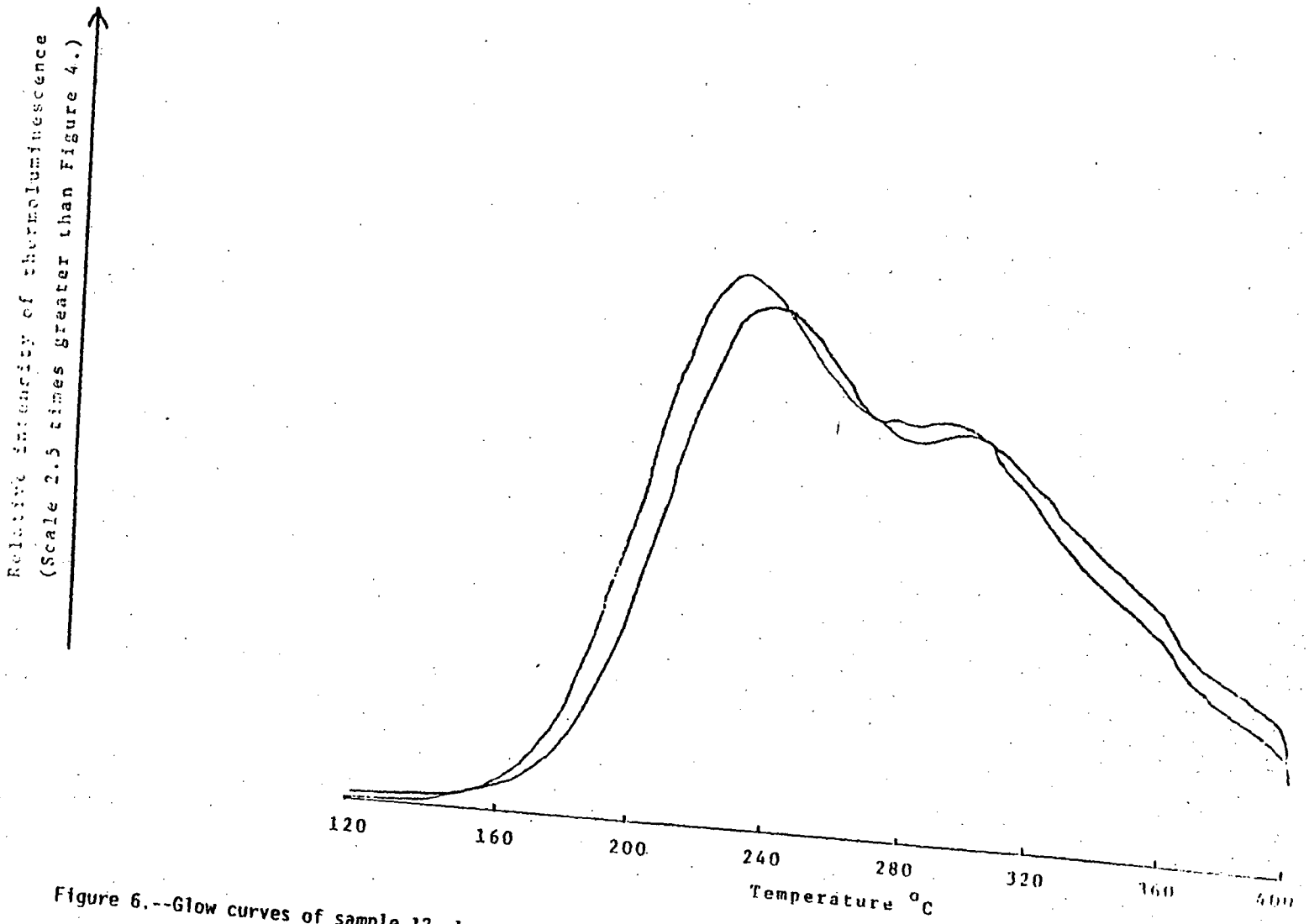

Figure 6.--Glow curves of sample 12, located nearest the ore on the updip side in the Powder River Basin, Wyo.

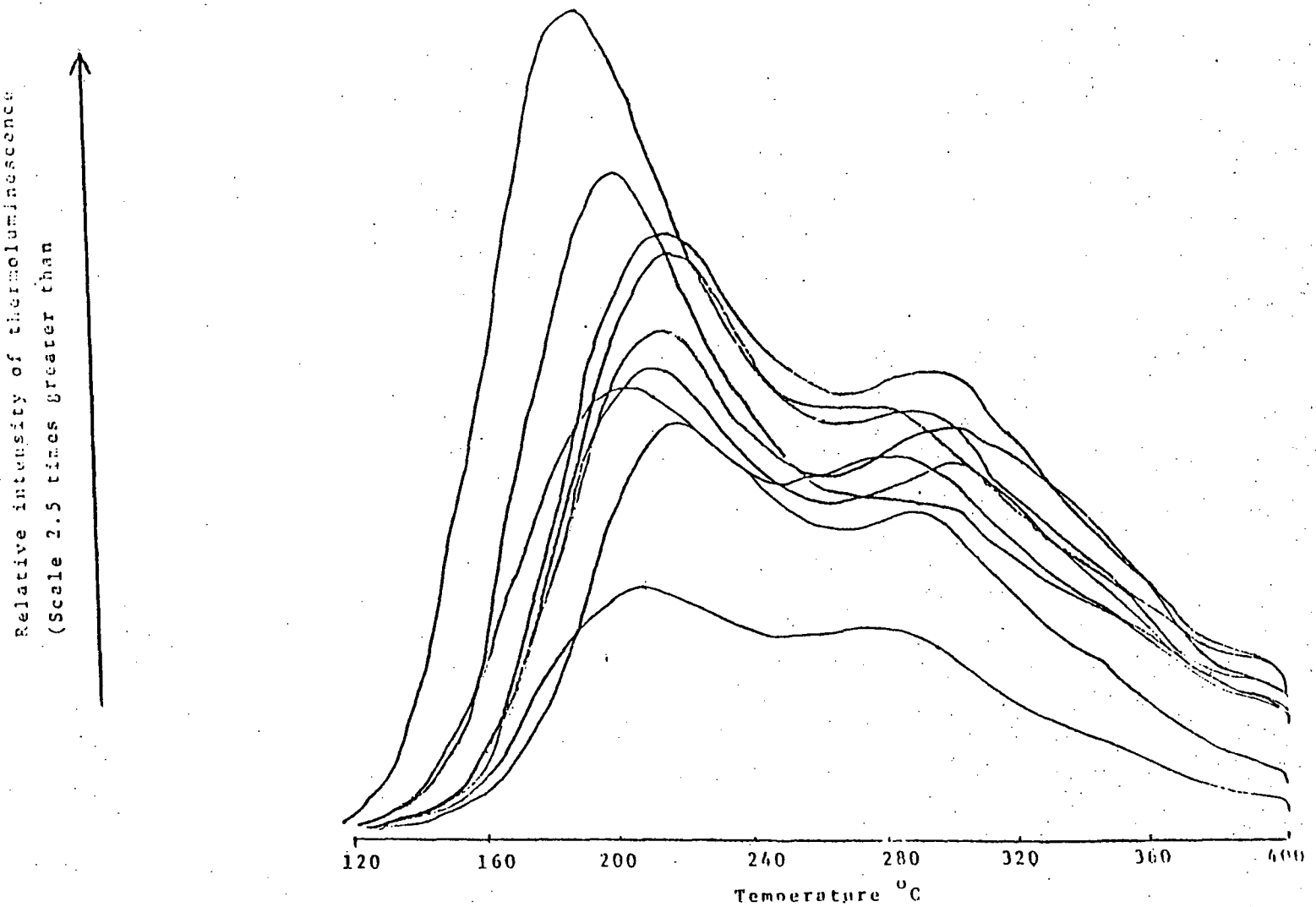

Figure 7.--Composite glow curves of mineralized samples 16, 21, 35, 42, and 47 in the Powder River Basin, Wyo.

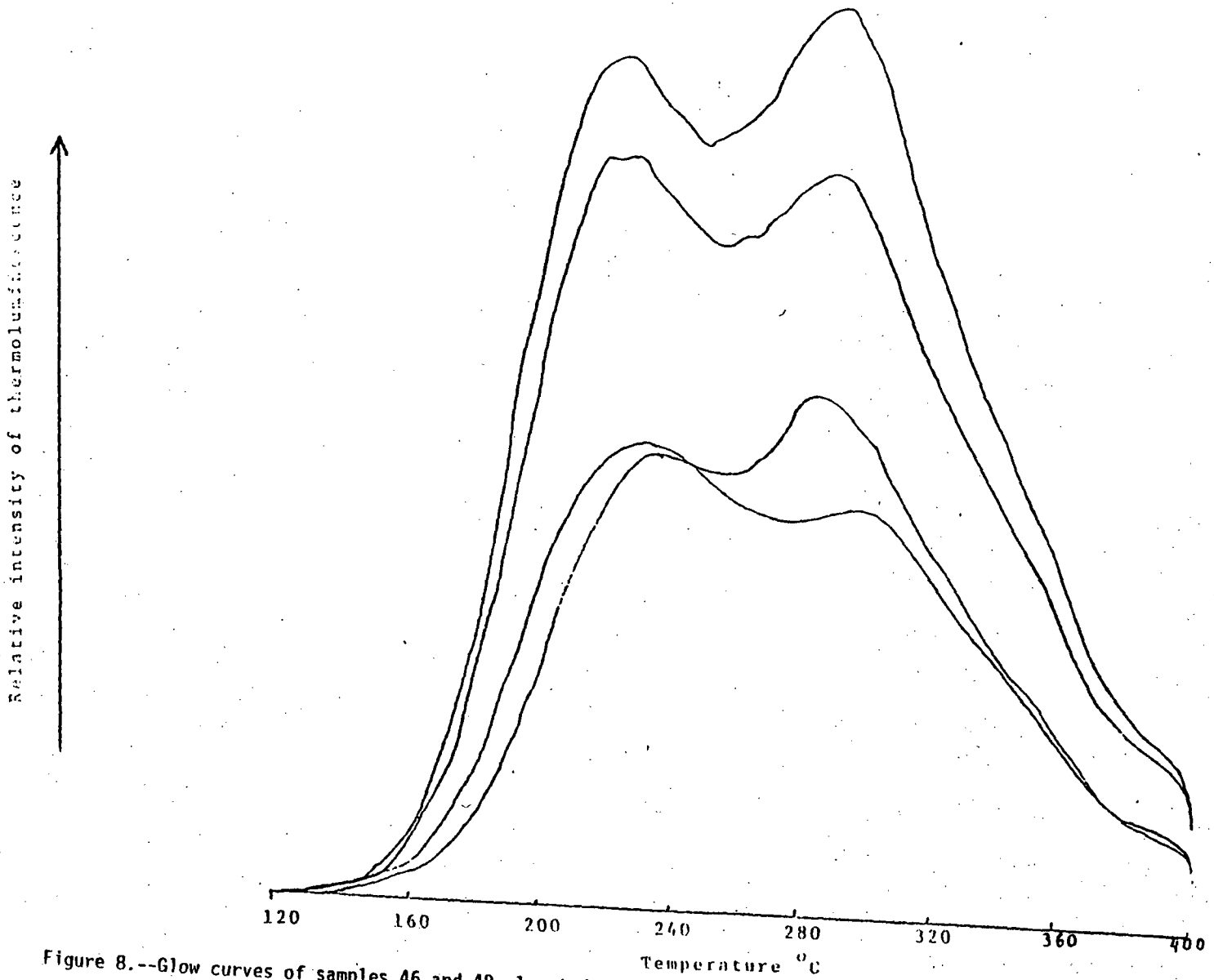

Figure 8.--Glow curves of samples 46 and 48, located downdip of the ore in the Powder River Basin, Wyo.

less than that of figures 6 and 7. The relative importance of low-temperature thermoluminescence to high-temperature thermoluminescence of figure 5 also lies between that of figure 4 and figures 6 or 7. Peaks in the intensity of thermoluminescence on the glow curves of mineralized samples (fig. 7) occur at lower temperatures than on the glow curves of unmineralized samples.

These observations of the characteristic shapes of glow curves around the orebody, and the knowledge that uranium roll-type deposits migrate, that radiation from uranium mineralization increases thermoluminescence in all temperature ranges (at least up to 400°C), and that low-temperature thermoluminescence fades faster than high-temperature thermoluminescence, may be used to predict the changes over time in the thermoluminescent glow curves of a sample exposed to radiation related to the migration of a uranium roll. (It is assumed here that the multiple accretion model of Gruner (1956) is correct and these data support Gruner's conclusion.) Figure 9A presents an idealized glow curve of a sample of quartz and feldspar grains undisturbed by mineralization; around an ore deposit, such a sample may be found in the reduced rock on the downdip side of the ore. In figure 9B, a uranium roll has migrated to the point of our sample. Radiation from the ore has increased the intensity of thermoluminescence in all temperature ranges. After the mineralized front has migrated farther downdip, the glow curve of our sample will look like figure 9C, which represents a sample that has been leached of mineralization but has not had sufficient time since leaching for the low-temperature thermoluminescence to fade completely to a background level. Such a sample is equivalent to the samples near the ore on the oxidized side. Because lower-temperature thermoluminescence fades faster than higher-temperature thermoluminescence, the lower-temperature portion of each peak decays faster than the higher-temperature portion of each peak; so as time

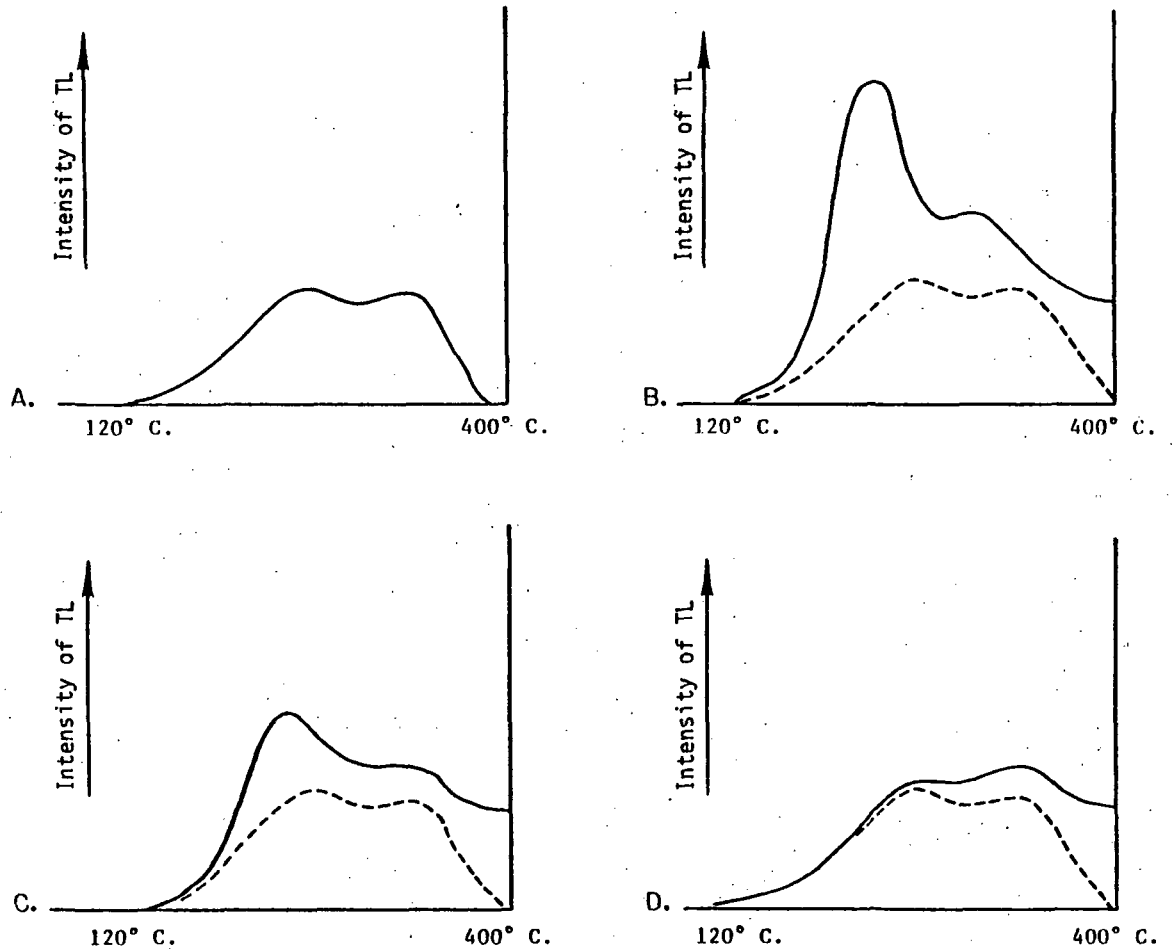

Figure 9.--Idealized pattern of changes in thermoluminescence (TL) glow curves with mineralization and leaching. Dashed line is premineralization glow curve. A, Premineralization (a point downdip not yet reached by the ore); B, mineralized; C, shortly after leaching (near the ore, updip); and D, longer after leaching (farther updip than C).

passes, the peak in the intensity of thermoluminescence progressively shifts to higher temperatures. This effect can be observed by comparing figures 9B, 9C, and 9D. In figure 9D, the low-temperature thermoluminescence has faded to near background levels thus causing the peak in the intensity of thermoluminescence to shift to higher temperatures and lowering the ratio of low-temperature to high-temperature thermoluminescence. On this glow curve (fig. 9D), only the high-temperature thermoluminescence records the previous radiation dose related to mineralization. Samples exhibiting this type of glow curve are expected to be found in the oxidized tongue updip from the mineralization and may be used as an indicator of mineralization downdip. Thus the observed glow curves and what is known about thermoluminescence may be reconciled to produce an idealized pattern of glow curves around a roll-type uranium deposit. Changes in the speed of migration of the mineralized front or in the intensity of mineralization along the front will cause deviations in the predicted pattern of glow curves but, at least for this deposit, such deviations are not so great as to obscure the effects of mineralization on the glow curves.

Conclusion

Ratios of thermoluminescent responses from different temperature ranges produced a pattern around this roll-type deposit similar to the pattern of ratios around a south-Texas roll-type deposit. Thus the contention that thermoluminescence may have application in uranium prospecting is supported. For the purpose of forming ratios, which successfully identify rock affected by the radiation associated with a migrating roll-type deposit, the division between low-temperature and high-temperature thermoluminescence may be anywhere from 180°C to 380°C. Ratios from all temperature ranges were successful and no clear optimum temperature ranges for ratioing were defined in this study.

Glow curves from samples on the updip side of the deposit which had been affected by the passage of the migrating roll front showed an increase in the importance of high-temperature thermoluminescence relative to low-temperature thermoluminescence. This increase in the importance of high-temperature thermoluminescence, which may be detected with ratioing or with glow curves, appears to be characteristic of former areas of mineralization associated with the migrating uranium roll front. Although some special care must be taken in handling thermoluminescence samples, and despite the lack of a detailed understanding of the causes of thermoluminescence, the ease of obtaining suitable samples (from cores, drilling chips, or outcrops), the virtual freedom from contamination by drilling muds, the low cost of the equipment, and the speed at which the thermoluminescence of a sample may be measured, suggest that thermoluminescence may have practical application in prospecting by identifying previously mineralized areas associated with various types of uranium deposits.

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