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Investigation into main luminescence properties of various natural salt samples using TL and OSL tecniques

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This study investigates the thermoluminescence (TL) and optically stimulated luminescence (OSL) properties of natural salt minerals to evaluate their potential for radiation dosimetry. Samples were sourced from the Central Anatolia region of Türkiye, the Himalayas (Asia), and Asal Lake (East Africa), and their dosimetric characteristics—including glow curve structure, dose-response, signal fading, and repeatability—were systematically analyzed.

All samples exhibited a highly linear dose-response relationship for irradiation doses between 0.1 and 10 Gy, with correlation coefficients (R^2) ranging from 0.991 to 0.999. The minerals demonstrated high sensitivity, with significant signal intensities produced by doses as low as 25 mGy. The TL glow curve structure was found to be dose-dependent, featuring three peaks at approximately 80–100°C, 125–190°C, and 230–290°C at low doses (0.1 Gy), and two dominant peaks at higher doses (10 Gy). A significant difference in signal stability was observed: while the OSL signal faded rapidly to background levels within approximately two seconds, the TL signal exhibited much greater stability.

The results confirm that the stable, reproducible, and dose-dependent TL signal of natural salt makes it a valuable, low-cost material for accident dosimetry. Further long-term fading studies are required to fully validate its potential for geological and archaeological dating.

Keywords: Thermoluminescence (TL), Optically Stimulated Luminescence (OSL), Radiation Dosimetry, Natural Salt, Luminescence Dating.

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Introduction

Thermoluminescence (TL) and Optically Stimulated Luminescence (OSL) are fundamental techniques employed in radiation dosimetry (Polymeris et al., 2011). The ongoing search for reliable and efficient dosimetric materials is driven by critical applications in environmental monitoring, personal dose assessment, and clinical physics. Within this field, passive dosimeters are especially advantageous. Their small size, low cost, and ability to function without external electronics make them highly suitable for a wide range of applications, including the measurement of high-dose radiation exposure (Rendell et al., 1991).

For many years, the thermoluminescent properties of natural salt minerals have been a subject of scientific inquiry, as it is well-established that these crystals exhibit luminescence. Natural salt is, after quartz and feldspar, the most abundant mineral in nature. Its luminescence properties are intrinsically linked to the presence of various impurities acquired from its geological formation environment, which act as trapping centers and activators for the dosimetric signal. Recent research has therefore focused on characterizing the kinetic and dosimetric properties of natural salt minerals sourced from various global regions (Bernhardsson et al., 2009).

Several studies have explored the dosimetric potential of salt. Research has been conducted on various forms, including household and culinary salts (Elashmawy et al., 2018; Khazal et al., 2010), and natural salts from specific geological locations like the Dead Sea (Azim et al., 2020). Other work has focused on characterizing the fundamental properties of sodium chloride (NaCl) for retrospective dosimetry and analyzing its TL spectrum using techniques like X-ray fluorescence (Spooner et al., 2011; Rodriguez-Lazcano et al., 2012; Druzhyna et al., 2016). More recently, investigations have extended to the effects of doping on the thermoluminescence of NaCl exposed to beta radiation (Khamis et al., 2021).

Building upon this body of work, the present study aims to provide a systematic investigation into the dosimetric properties of natural salt samples from Türkiye and other regions. The primary objectives are:

- To investigate key luminescence properties – including dose response, linearity, signal fading, repeatability, thermal quenching, and sensitivity – of natural salt samples irradiated with beta particles, using both TL and OSL signals.
- To evaluate the overall dosimetric performance of these salt samples to determine their suitability as inexpensive, readily available, and reliable alternative dosimeters.

I. Materials and discussion

II.I. Sample Origin and Preparation

The salt samples investigated in this study were obtained from salt deposits in the Central Anatolia region of Türkiye, a product of the Tethys Ocean which covered the area millions of years ago. To broaden the scope of the investigation, additional samples were sourced from the Himalayas (Asia) and Asal Lake (Djibouti, Africa). A complete list of the samples and their assigned codes is provided in Table 1.

Table 1.
Source and assigned codes for the natural salt samples

Sample Code	Type of Natural Salt Samples	Origin
AGT	Asal Lake Salt	Lake Asal (Djibouti, Africa)
CKKTJ	Çankırı Crystal Rock Salt (J)	Çankırı, Türkiye
CBT	Cihanbeyli Salt	Cihanbeyli, Türkiye
GT	Lake Salt	Salt Lake (Tuz Gölü), Türkiye
KT	Kırşehir Salt	Kırşehir, Türkiye
HT	Himalaya Salt	Himalayas (Asia)
ST	Sole Salt	Çankırı, Türkiye
CIT	Çankırı İskilip Salt	İskilip, Çankırı, Türkiye
TGT	Tuz Lake Salt	Salt Lake (Tuz Gölü), Türkiye
CT	Çankırı Salt	Çankırı, Türkiye
KKT	Kırıkkale Salt	Kırıkkale, Türkiye
TGKT	Tuz Lake (Kayseri) Salt	Tuzla Lake, Kayseri, Türkiye

For sample preparation, all materials were carefully crushed into a fine powder using an agate pestle and mortar. The powder was then sieved to isolate a uniform grain size of 125–160 µm for all experiments. To remove any pre-existing luminescence signals and standardize the thermal history, the sieved samples were pre-annealed in a furnace at 500°C for one hour.

For analysis, aliquots of approximately 50 mg of the prepared salt were placed in standard stainless-steel cups from Risø National Laboratory, Denmark. Mass reproducibility for the aliquots was maintained within a ±5% error.

II. II. Luminescence Measurement Protocol

All luminescence measurements were performed at the Ankara University using a Risø TL/OSL reader (model TL/OSL-DA-20). The reader is equipped with a $^{90}Sr/^{90}Y$ beta particle source that delivers a nominal dose rate of 0.111 ± 0.004 Gy/s. The source was calibrated against a reference quartz standard.

For Thermoluminescence (TL) measurements, a linear heating rate of 5 °C/s was applied up to a maximum temperature of 400 °C, with two data points recorded per degree Celsius (Veronese et al., 2010).

For Optically Stimulated Luminescence (OSL) measurements, samples were stimulated with a blue LED (470 ± 20 nm) delivering a maximum power of 50 mW/cm² at the sample position (Kitis et al., 2015). The resulting OSL signal was detected through a 7.5 mm Hoya U-340 filter (peak transmission at $\lambda p \approx 340$ nm, FWHM ≈ 80 nm), using a 9635QA photomultiplier tube.

A test dose of 10 Gy was used for all TL and OSL dose-response, fading, and repeatability measurements.

II. Results and analysis

III.I TL and OSL Dose-Response

A fundamental requirement for any material used in dosimetry is a predictable and reproducible relationship between the absorbed radiation dose and the resulting luminescence signal. The natural salt samples in this study demonstrated excellent dose-response characteristics for both TL and OSL signals.

The TL dose-response was found to be highly linear within the applied dose range of 0.1–10 Gy. The correlation coefficients (R^2) for the linear fits ranged from 0.991±0.03 to 0.999±0.003 across all samples, indicating a strong positive correlation. As a representative example, Figure 1 shows the TL characteristics for the Sole salt (ST) sample. The TL glow curve (Figure 1a) is characterized by two distinct peaks centered at approximately 105 °C and 315°C. The intensity of these peaks grows proportionally with the increasing dose, and the resulting dose-response curve (Figure 1b) shows an excellent linear fit. This linear behavior was consistent across all materials studied, as shown in the combined dose-response plot in Figure 2.

Similarly, the OSL dose-response was found to be linear for all samples within the 1–10 Gy range. Figure 3 illustrates the OSL characteristics for the Sole salt (ST) sample, where the OSL signal decays rapidly and the integrated luminescence shows a clear linear relationship with the dose. This consistent linear trend is further demonstrated in the combined OSL dose-response curves for all samples, presented in Figure 4.

This confirmed linearity for both TL and OSL is a critical finding. It validates the potential of these natural salts for use in dosimetry, as it allows for the accurate and straightforward reconstruction of an unknown absorbed dose. These results are in strong agreement with previous studies on natural salts from other regions, such as the Jordanian Dead Sea salt reported by Azim et al. (2020).

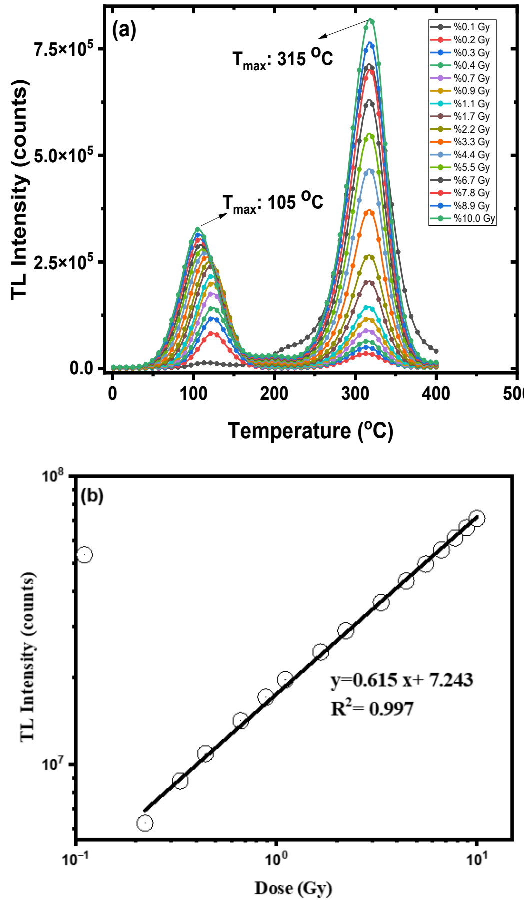

Fig. 1. Thermoluminescence (TL) characteristics of the Sole salt sample (ST). (a) Glow curves are shown as a function of increasing radiation dose. (b) The corresponding linear dose-response curve, with an R^2 value of 0.997, demonstrates a strong correlation.

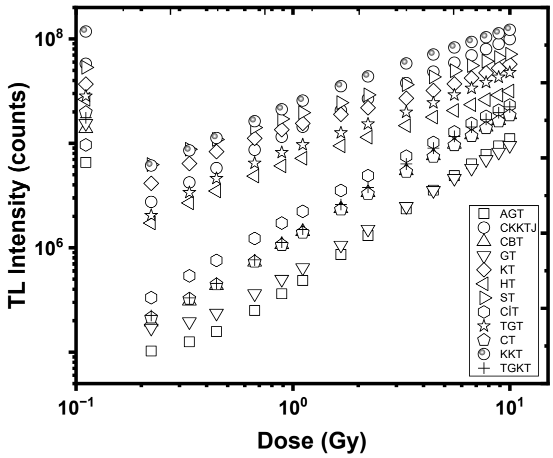

Fig. 2. Combined TL dose-response curves for all natural salt samples, showing consistent linear behavior across the tested dose range.

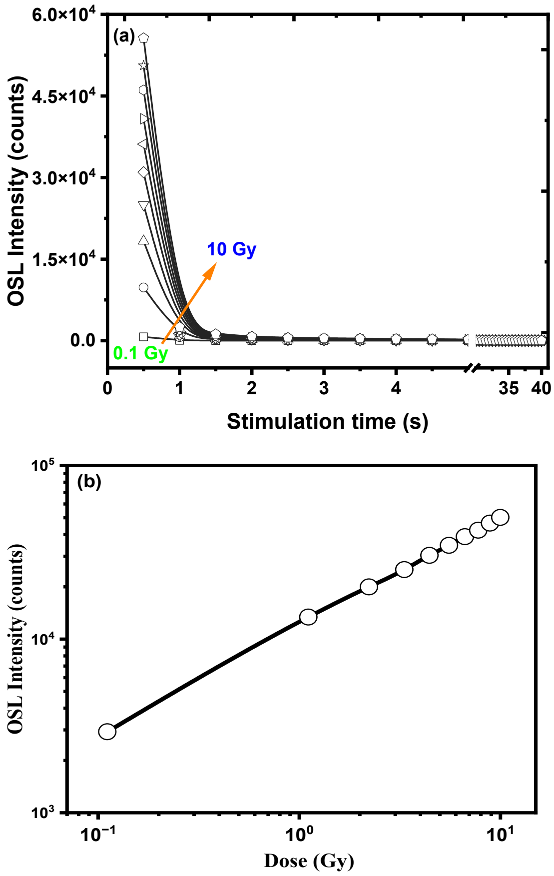

Fig. 3. Optically Stimulated Luminescence (OSL) characteristics of the Sole salt sample (ST). (a) OSL decay curves for various radiation doses. (b) The corresponding linear dose-response curve confirms a predictable relationship.

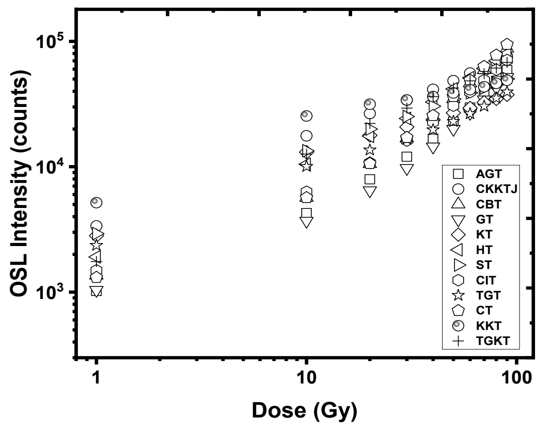

Fig. 4. Combined OSL dose-response curves for all natural salt samples, demonstrating a consistent linear trend.

III.II Fading and Signal Stability

The stability of the luminescence signal over time (fading) is a crucial characteristic for a dosimeter, as it determines the time window within which an accurate dose can be measured after irradiation. To assess this, fading characteristics were evaluated for all samples following irradiation with a 10 Gy dose. The samples were stored in darkness at room temperature for one week, after which their TL and OSL signals were remeasured.

The TL signals exhibited considerably greater stability, with signal loss for most samples ranging from 20.4% to 60.8%. Interestingly, a few samples (CT, KKT, TGKT) showed a slight signal increase, a phenomenon known as anomalous fading, which can occur due to charge transfer between trap levels during storage.

The quantitative results of the fading experiment are summarized in Table 2. The OSL signals showed significant fading across all samples, with signal loss ranging from 82.9% to 94.6% after one week. In contrast, the TL signals exhibited considerably greater stability, with signal loss ranging from 20.4% to 60.8%. The graphical comparison of signal intensities measured immediately after irradiation versus after the one-week fading period is shown in Figure 5.

Table 2.

eComparison of TL and OSL signal intensities for samples irradiated with 10 Gy, measured immediately and after one week, to quantify signal fading.

Sample Code	Total TL Intensity (x 10^8 counts)	Total OSL Intensity (x 10^5 counts)
	Immediately After	After 1 Week
AGT	1.08	0.43
CKKTJ	6.12	4.66
CBT	3.33	2.32
GT	10.00	5.25
KT	7.25	4.37
HT	3.33	2.65
ST	9.03	4.89
CIT	5.35	3.85
TGT	5.51	3.86
CT	3.91	4.87
KKT	2.34	2.47
TGKT	1.78	1.81

To further analyze the stability of the TL signal, the individual glow peaks of the Sole salt (ST) sample were deconvoluted. As shown in Figure 6, the analysis revealed that the highest signal loss occurred at the second, higher-temperature peak.

The fading results have direct implications for the potential applications of these materials. The rapid and significant fading of the OSL signal makes it unsuitable for retrospective dosimetry or dating, where there is often a considerable delay between the radiation event and measurement.

The TL signal, however, is far more stable. Its moderate fading makes it a promising candidate for accident dosimetry, where dose reconstruction may occur days or weeks after an event. While the observed stability of the TL signal is promising for short-term dosimetry, it must be noted that a one-week fading assessment is not sufficient to validate the material for long-term dating applications. A comprehensive, long-term fading study is therefore essential to establish the signal's decay pattern and develop accurate correction protocols for such applications. For such applications, which involve timescales of hundreds or thousands of years, a comprehensive, long-term fading study is essential to establish the signal's decay pattern and develop accurate correction protocols. Therefore, while our results support the use of TL for short-term retrospective dosimetry, further research is required to confirm its utility for long-term dating.

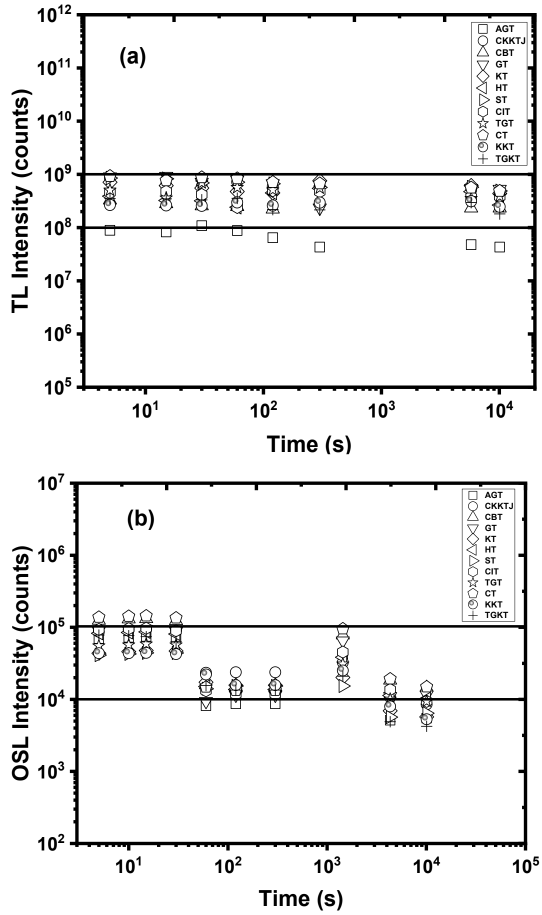

Fig. 5. Comparison of (a) TL and (b) OSL signal intensities measured immediately after irradiation (10 Gy) and after a one-week fading period for all salt samples. The graphs visually demonstrate the significantly higher fading rate of the OSL signal compared to the TL signal.

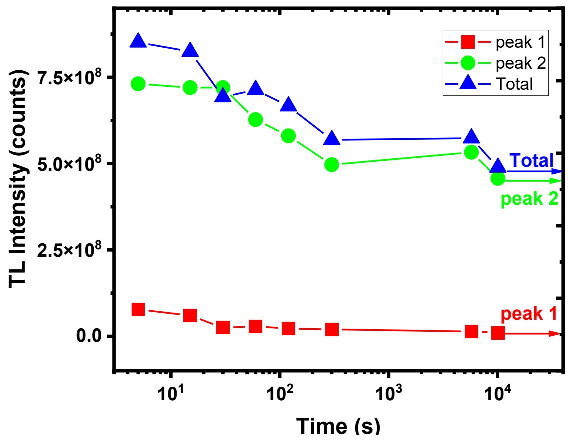

Fig. 6. Deconvoluted TL fading analysis for the Sole salt sample (ST). The graph illustrates the relative fading rates of peak 1, peak 2, and the total integrated signal over time, indicating that the higher-temperature peak is less stable in this case.

III.III Repeatability

Besides linearity and stability, a reliable dosimeter must exhibit high repeatability, meaning it produces a consistent signal for the same given dose over multiple measurement cycles. To evaluate this, natural salt samples were irradiated with a 10 Gy dose, and their TL and OSL signals were recorded over 10 repeated cycles.

The measurements, performed at room temperature, demonstrated excellent repeatability for both TL and OSL signals. As shown for the representative Sole salt (ST) sample in Figure 7, the variance between measurements was minimal. This high degree of consistency was observed across all samples, as illustrated in the combined repeatability data in Figure 8. The standard deviation of the repeated measurements was found to be less than 5% for all samples, which is well within the acceptable limits for dosimetry.

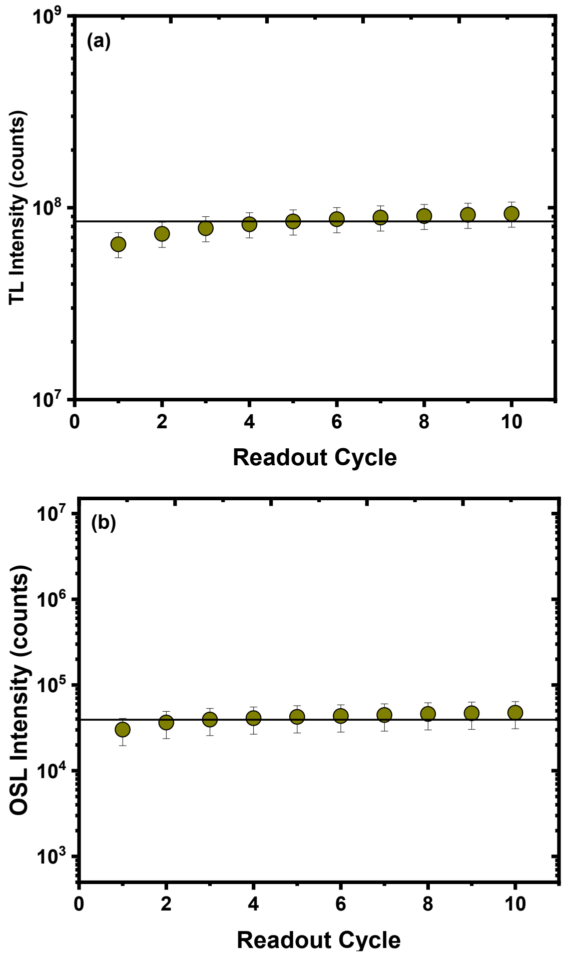

Fig. 7. Repeatability of (a) TL and (b) OSL signals for the Sole salt sample (ST) following 10 repeated irradiation cycles with a 10 Gy dose. The minimal variation in signal intensity highlights the excellent reproducibility of the measurements.

This result is consistent with findings from similar studies, such as that by Bulcar et al. (2022), who reported a variance of less than 1% for rock salt from the Tuzluca region of Türkiye. The high repeatability found in our study further strengthens the case for using these natural salts as reliable dosimeters, as it ensures that measurements are both accurate and reproducible.

III.IV Thermal Quenching

Thermal quenching is a phenomenon where the luminescence efficiency of a material decreases at higher temperatures, which can affect the shape and intensity of the TL glow curve, particularly at high heating rates. The effect of thermal quenching was investigated by performing TL measurements at various heating rates (β = 1, 2, 5, 7, 10, 14, and 25 °C/s) up to a maximum temperature of 400°C.

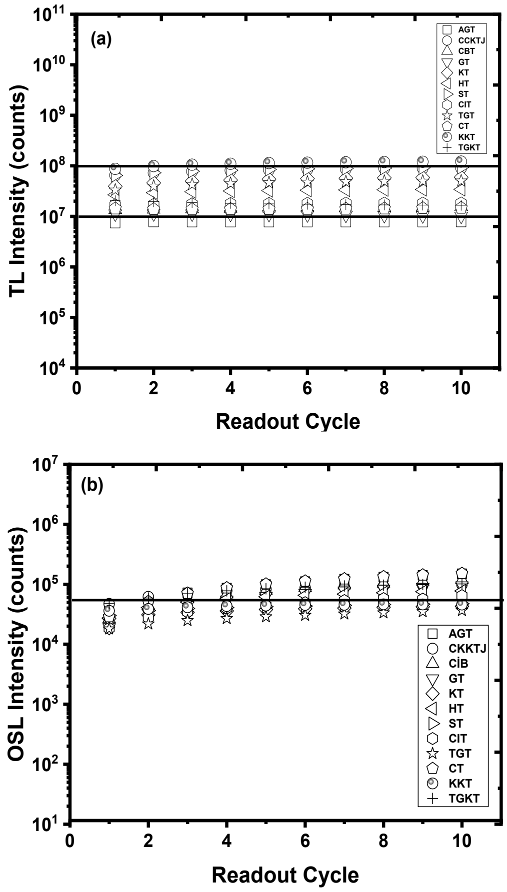

Fig. 8. Combined repeatability data for all salt samples. (a) TL signal intensity and (b) OSL signal intensity measured over 10 consecutive irradiation cycles (10 Gy) show consistently low variance.

Typically, thermal quenching manifests as a decrease in the integrated area under the TL glow curve as the heating rate increases. However, in this study, we observed the opposite effect. For all salt samples, an increase in the total TL signal intensity was observed with increasing heating rates, as shown for the Sole salt (ST) sample in Figure 9a and for all samples in Figure 9b.

This unexpected increase in signal intensity suggests the absence of thermal quenching in these natural salt minerals. Instead, this behavior may indicate a transfer or transformation of charge carriers within the trap centers of the salt's crystal lattice during the heating process, a phenomenon previously suggested by Spooner et al. (2011). This finding is significant as it shows that the TL signal is robust and not susceptible to efficiency loss at higher heating rates, which provides flexibility in designing measurement protocols.

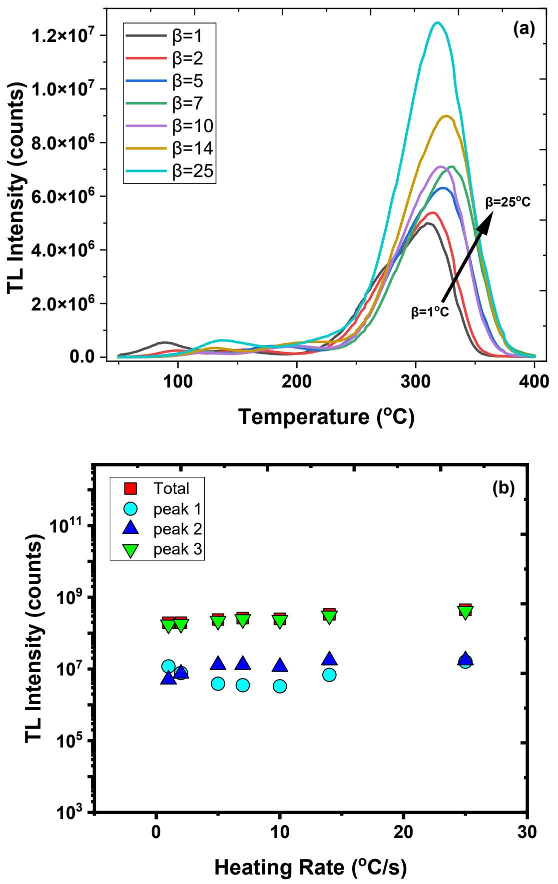

Fig. 9. Investigation of thermal quenching. (a) Effect of different heating rates (β) on the TL glow curve of the Sole salt sample (ST). (b) Integrated TL signal intensity as a function of heating rate for all salt samples, showing a consistent increase in signal, which indicates the absence of thermal quenching.

Conclusion

This study successfully characterized the dosimetric properties of natural salt minerals from various geographical regions using thermoluminescence and optically stimulated luminescence techniques. The investigation confirmed that these widely available and low-cost materials possess key characteristics that make them highly suitable for radiation dosimetry.

The main findings of this work are as follows:

- The salt samples exhibited a highly linear dose-response for both TL (0.1–10 Gy) and OSL (1–10 Gy) signals, which is essential for accurate dose reconstruction.
- The materials showed high sensitivity, capable of producing a significant luminescence signal even at low radiation doses.
- Measurements demonstrated excellent repeatability over multiple cycles, with a variance of less than 5%, confirming the reliability of the dosimetric signal.
- A significant difference in signal stability was observed. The OSL signal faded rapidly, limiting its use, while the TL signal showed much greater stability, making it suitable for retrospective dosimetry.
- The TL signal intensity increased with higher heating rates, indicating an absence of thermal quenching and suggesting that the material's luminescence efficiency is strong during measurement.

The findings confirm that natural salt is a viable and promising material for accident dosimetry, where its stable TL signal, high sensitivity, and low cost are significant advantages. While its potential for geological and archaeological dating is noted, further research is required. Specifically, comprehensive long-term fading studies are needed to develop the correction protocols necessary for accurate dating applications.

Future work should also focus on quantifying the influence of specific impurities and mineralogical composition on the luminescence efficiency of salts from different origins. Understanding this relationship could be crucial for standardizing the use of natural salt as a reliable dosimeter.

Author Contributions

Both authors contributed equally to this work.

Declaration of competing interest

The authors declare they have no competing financial or personal interests that could have inappropriately influenced the work reported in this paper.

Kavas Yasemin – Ph.D. student;
Şahiner Eren – Ph.D.

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Дослідження люмінесцентних властивостей природних зразків солі методами TL та OSL

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У цьому дослідженні проаналізовано властивості термолюмінесценції (TL) та оптично стимульованої люмінесценції (OSL) природних мінералів солі для оцінки їхнього потенціалу у радіаційній дозиметрії. Зразки були зібрані в Центральній Анатолії (Туреччина), Гімалаях (Азія) та озері Асаль (Східна Африка), а їхні дозиметричні характеристики – зокрема структура кривих світіння, залежність сигналу від дози, згасання сигналу та відтворюваність – були систематично досліджені. Усі зразки продемонстрували високу лінійність дозової залежності в інтервалі 0,1–10 Гр, із коефіцієнтами кореляції (R^2) у межах 0,991–0,999. Мінерали виявили високу чутливість, забезпечуючи значні інтенсивності сигналу вже за опромінення дозами від 25 мГр. Структура TL-кривих виявила дозозалежний характер: при низьких дозах (0,1 Гр) зафіксовано три піки (~80–100 °C, 125–190 °C, 230–290 °C), тоді як при вищих дозах (10 Гр) спостерігалися два домінантні піки. Встановлено суттєві відмінності у стабільності сигналів: сигнал OSL швидко згасав до фонового рівня приблизно за дві секунди, тоді як TL-сигнал залишався значно стабільнішим. Отримані результати підтверджують, що стабільний, відтворюваний та дозозалежний TL-сигнал природних соляних мінералів робить їх перспективним і економічно доступним матеріалом для аварійної дозиметрії. Водночас для повного підтвердження їхнього потенціалу у геологічному та археологічному датуванні потрібні додаткові довгострокові дослідження згасання.

Ключові слова: термолюмінесценція (TL); оптично стимульована люмінесценція (OSL); радіаційна дозиметрія; природна сіль; люмінесцентне датування.