Environment and Natural Resources Journal

Volume 24
Issue 5
2026

# The White Sands of Tutong - A High Quality Sand Suitable for Photovoltaic Applications

**Stefan Herwig Gödeke[1*], Nurizz Syuhaidah Rahmadi[1], Pg Emeroylariffion Abas[2], Afiq Aiman Jaya[3], Muhammad Asri Akmal Hj Suhip[3], Jens Walter[4,5], Gundula Helsch[6], and Joachim Deubener[6]**

[1]*Geoscience Programme, Universiti Brunei Darussalam, Jalan Tungku Link, BE1410, Brunei Darussalam*
[2]*Faculty of Integrated Technologies, Universiti Brunei Darussalam, Jalan Tungku Link, BE1410, Brunei Darussalam*
[3]*Geology Research Unit, Department of Technical Services, Public Works Department, Brunei Darussalam*
[4]*Geoscience Center, Georg-August University Göttingen, Goldschmidtstraße 1-3, 37077 Göttingen, Germany*
[5]*MASA Institute GmbH, Friedrichstr. 3-4, 37073 Göttingen, Germany*
[6]*Institute of Non-Metallic Materials, Clausthal University of Technology, 38678 Clausthal-Zellerfeld, Germany*

## ARTICLE INFO

Received: 10 Dec 2025
Received in revised: 4 Jun 2026
Accepted: 8 Jun 2026
Published online: 26 Aug 2026
DOI: 10.32526/ennrj/24/20250368

**Keywords:**
Brunei/ Glass melt/ High purity Quartz/ Silica sand/ Solar transmittance

*** Corresponding author:**
E-mail:
stefan.godeke@ubd.edu.bn

## ABSTRACT

The renowned White Sands of Tutong in Brunei Darussalam, situated on the island of Borneo, have long been recognized as a potential source of glass-grade sand. As Brunei Darussalam seeks to diversify its economy, these sand deposits are gaining attention as a valuable mineral resource for sustainable development. Lithological investigations showed that the deposit is geologically more heterogeneous than anticipated, with the groundwater table close to the surface and the presence of red-brown sand indicating higher iron concentrations in current or former water-table fluctuation zones. This study investigated the chemical properties of the sand via ICP-OES, and XRF, which confirmed the high purity of the silica sand with low concentrations of iron. The glass produced from the raw sand exhibited a solar transmittance of 90.2%, making it suitable for photovoltaic applications. The sand should be shielded from any further development, like housing development and any development should carefully weigh the economic versus the ecological value of the sand as it also supports a rare tropical heath ecosystem.

## HIGHLIGHTS

- Glass from the White Sands shows high solar transmittance for photovoltaic use.
- The deposit is more geologically heterogeneous than previously understood.
- Development must balance economic and ecological value and protect the deposit.

## 1. INTRODUCTION

Since the dawn of time, humans have used sand for shelter and development purposes. Sand is formed through chemical weathering and erosive processes over millions of years. Quartz sands are suitable for a wide range of industrial applications (Harben, 2002; Platias et al., 2014; Pan et al., 2022). In high-technology industries, quartz is a critical raw material used in photovoltaic cells, silicon wafers, fiber optics, and other advanced components. In particular, high-purity silica sand is essential for producing silicon, which forms the foundation of solar panels and semiconductor devices. The increasing demand for photovoltaic and semiconductor technologies has led to a growing dependence on high-purity quartz sand as a critical raw material.

For solar applications, silica sand must meet stringent chemical and mineralogical requirements. Iron (<0.02 wt% $Fe_2O_3$), titanium (0.03 wt % $TiO_2$) and chromium (0.0005 wt% Cr) must be present only in trace amounts, as these impurities can reduce the performance and efficiency of photovoltaic materials (Vogt et al., 2016; Treviño Rodríguez et al., 2023). A consistent grain size, ranging between 0.1 to 0.6 mm (Schweiger et al., 2010; Elsner, 2016), is also necessary for industrial processing. For electronics,

**Citation:** Gödeke SH, Md Izahr Ramahdi NSH, Abas PE, Jaya AA, Suhip MAAH, Walter J, Helsch G, Deubener J. The white sands of Tutong - A high quality sand suitable for photovoltaic applications. Environ. Nat. Resour. J. 2026;24(5):631-641. (https://doi.org/10.32526/ennrj/24/20250368)

including solar cells, silica sand must exhibit extremely high quartz purity (>99.6% $SiO_2$) and minimal impurities to ensure reliable performance.

Solar photovoltaics are experiencing rapid growth, with China leading in installed capacity, followed by the European Union, the United States and India (Chowdhury et al., 2025). While some countries can meet their silica sand needs through domestic resources, others rely on imports (Burkowicz et al., 2020). Growing global demand, particularly for renewable energy infrastructure, has intensified pressure on existing sand sources. In many regions, overexploitation of sand has led to ecosystem degradation, biodiversity loss, and shoreline erosion, with negative consequences for human and environmental health (Bendixen et al., 2021). River sand mining is highly damaging, as it disrupts drainage networks and causes lasting ecological harm (Rentier and Cammeraat, 2022). A recent study in Brunei found that dredging and quarrying near the Brunei River had significantly increased turbidity (Onifade et al., 2023), underscoring the importance of baseline assessments for evaluating environmental impact (Oluwaniyi and Asiwaju-Bello, 2020).

Brunei Darussalam experienced substantial shoreline erosion and flood risk due to coastal sand mining in the 1950s (Chua et al., 1987; Yong, 2010; Latif and Yong, 2021), which led to the cessation of such practices. However, recent highway construction has involved sand abstraction beneath coastal peatlands, leading to drainage impacts on tropical peatlands (Suhip et al., 2020). Globally, sand is being extracted far more rapidly than it is naturally replenished. This is especially true in high-income countries, which consume ten times more raw materials than low-income ones (Schandl et al., 2018). Between 2020 and 2060, global demand for construction-grade sand is projected to rise by 45%, emphasizing the urgency for sustainable extraction practices (Zhong et al., 2022).

Sand and gravel now represent the largest share of solid material use—surpassing fossil fuels and biomass—and have experienced the fastest growth in demand (Torres et al., 2017; Krausmann et al., 2009). Unfortunately, Southeast Asia has become a global hotspot for both legal and illegal sand extraction (Park, 2024; Yuen et al., 2024).

Brunei Darussalam is actively seeking to diversify its economy beyond fossil fuels; priority sectors include high-tech industries such as semiconductors, fiber optics, advanced manufacturing and high-tech agriculture have been identified for development (Radzuan et al., 2022). These high-tech industries rely heavily on secure access to strategic raw materials, including high-purity quartz. To support this national vision, Brunei is pursuing sustainable mining strategies and formulating green operational guidelines aimed at ensuring long-term resource availability and environmental stewardship.

The current works builds upon an earlier investigation (Gödeke et al., 2025) which examined the glass-making potential of the White Sands of Tutong and concluded that their high silica content compares favorably with other international silica sand deposits (Boussaa Anas, 2020). Expanding on these findings, the present study focuses on assessing the optical properties of glass derived from the sand, particularly for solar applications. Given the absence of updated geological data—most of which dates back to the 1950s and 1980s—this research also aims to expand the current knowledge on Brunei's White Sands of Tutong; by undertaking detailed lithological investigations through the excavation of sacrificial boreholes using a hand auger. Additional modern analytical methods were applied to assess the deposit's potential for high-tech and photovoltaic applications.

## 2. METHODOLOGY

### 2.1 Data visualization and cross-section construction

ArcGIS Pro 3.1.0 was used to generate an overview map of the study site (Figure 1), while Strater (Golden Software, Version 5.7) was used to construct the geological cross-section profile based on borehole data. The Strater software allows for the correlation of matching stratigraphic units between boreholes based on depth and contact points; if a unit was present in one borehole but was absent in the adjacent one, it was assumed to pinch out, forming a wedge-shaped polygon in the profile.

### 2.2 Field sampling

Lithological investigations were conducted using a bayonet hand auger (Edelman type for sandy soil, Royal Eijkelkamp). Sacrificial boreholes for lithological investigations were spaced around 500 m to 2 km apart depending on site accessibility, and were fully backfilled after sampling. Coring was limited to a maximum depth of 3 m below the surface due to the increasing difficulty of hand augering, particularly when the groundwater table was encountered. For geochemical analysis, quartz sand samples were collected near borehole 5 using a small shovel and stored in a sampling bag before being transferred to the laboratory.

### 2.3 Geochemical analysis

Trace element concentrations were measured at the MASA Institute (Göttingen, Germany) using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES; iCAP Pro XP, Thermo Scientific) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS; iCAP TQe, Thermo Scientific). This means that after complete digestion using HF-$HNO_3$-HCl, the samples were diluted 1:1,000 with 2% $HNO_3$ so that they could be measured by the instruments. The dual approach of using ICP-OES and ICP-MS was chosen for quality control and analytical reasons. For example, sulfur was analyzed using ICP-OES due to spectral interferences and its ionization behavior in ICP-MS. Prior to glass preparation, the sand was dry sieved, and the grain-size fraction between 125 µm (ASTM No. 120) and 355 µm (ASTM No. 45) was retained. This fraction was washed 4 times with demineralized water, with excess water decanted after each wash, and subsequently dried in a drying cabinet at 90°C. A typical soda-lime float glass composition (74 mol% $SiO_2$, 16 mol% $Na_2O$, 10 mol% CaO) was chosen, as soda-lime float glass is widely used in solar panel manufacturing due to its low cost, mechanical strength, and ease of mass production. For the glass batch, 88.8 g of $SiO_2$, 34 g of $Na_2CO_3$, and 20 g of $CaCO_3$ were used, totaling 142.8 g based on the molar compositions. The $Na_2CO_3$, with a purity of greater than 99.9%, was sourced from Merck and the $CaCO_3$, with a purity of 99.95%, from Strem Chemicals.

### 2.4 Glass synthesis and optical characterization

The glass melting and subsequent analysis were conducted at the Institute of Non-Metallic Materials, Clausthal University of Technology, Germany. The batch mixture was heated in a platinum crucible up to 1,550°C in the oven over a period of 2 h and kept at this temperature for 1 h for homogenization. The glass melt was then cast in a graphite mold with the dimensions of 40×40×20 mm and transferred into a cooling furnace for relaxation at 550°C for 4 h, followed by cooling down to room temperature within 10 h. From the glass block, a slice approximately 20×20 mm, with a thickness of 3 mm, was cut and polished up to grit 4,000 to obtain a very smooth polished surface suitable for optical analysis.

The transmission spectrum of the prepared glass slice was measured using a PerkinElmer Lambda 950 UV-Vis-NIR spectrophotometer equipped with an integrating sphere (150 mm) and solar transmittance was calculated according to DIN EN 410. In this norm the average transmittance in the wavelength ranges from λ=300 to 2,500 nm is weighted by the air mass 1.5 radiation and calculated as

$$\tau = \frac{\int_{300\ \mathrm{nm}}^{2,500\ \mathrm{nm}} \tau_\lambda \times S_\lambda \times d\lambda}{\int_{300\ \mathrm{nm}}^{2,500\ \mathrm{nm}} S_\lambda \times d\lambda} \tag{1}$$

where; $T_\lambda$ is the wavelength-dependent transmittance of the coated glass and $S_\lambda$ the solar radiation function for air mass 1.5 (ASTM G173-03). The glass composition was analysed using an energy dispersive X-ray fluorescence spectrometer (XRF), Model EDX-700P, Shimadzu.

Primitive mantle-normalized multi-element spider diagrams were generated using normalization values from McDonough and Sun (1995), enabling assessment of trace element enrichment and depletion patterns relative to bulk silicate Earth composition. In addition, a chondrite normalized REE-pattern graph was generated.

### 2.5 Study site

Located near Tutong town in Brunei Darussalam, approximately 60 km from the capital Bandar Seri Begawan, the White Sands of Tutong represent a significant silica sand deposit (Figure 1). First documented by Wilford (1961), the deposit is believed to be the remnant of an ancient beach dune system formed during a marine transgression. The silica sand deposit stretches approximately 11 km in length and 2 km in width and is intersected by the Seria-Tutong highway: with the sands forming terraces rising to about 15 meters above sea level and overlying flat Quaternary clay deposits (Sandal, 1996). A recent study by Gödeke et al. (2025) redefined the extent of the deposit, highlighting notable discrepancies between the original boundary proposed by Wilford and the updated delineation, likely due to both improved geological surveying techniques and natural changes in surface features over time.

Previous observations identified two primary sand layers: an upper white fine sand ranging from 0.6 to 4.6 meters thick, and a lower humus-stained fine sand. The estimated volume of the white sand layer is approximately 15 million m³ (Sandal, 1996). Notably, the site also supports a rare tropical heath forest ecosystem (Din et al., 2015), underscoring the need for any future development to balance ecological preservation with the potential for mineral exploitation (UNEP, 2019).


**Figure 1.** Study site with extent of silica sand and location of hand-augered boreholes, Tutong, Brunei Darussalam

## 3. RESULTS AND DISCUSSION

This section presents the findings from the lithological investigation, geochemical analysis of the silica sand, and optical characterization of the glass product derived from the White Sands of Tutong.

### 3.1 Study area and geological setting

The lithological profile obtained from the hand-augered boreholes is shown in Figure 2. The results of the lithological investigations clearly show that the sand deposit is not composed solely of white fine sand, which had previously been characterized as a moderately well sorted fine sand, with symmetrical graphic skewness and mesokurtic graphic kurtosis (Gödeke et al., 2025). The present investigation reveals a more heterogeneous stratigraphy, with the white sand facies forming a dominant and continuous upper layer across most boreholes, except where it is truncated by overlying blackish, grey, or red-brown sands.

In particular, BH1 to BH3 show interruptions of the white sand layer by overlying black and red-brown sands, indicating facies variation, possible surface reworking, or post-depositional alteration in the northwestern part of the deposit. Black sand, encountered in these boreholes, is rich in organic matter and often lies above either red-brown or white sand, suggesting dynamic depositional processes or subsequent transformation under reducing conditions. The red-brown sands were already observed by Wilford (Wilford, 1961) and appear discontinuous across these locations. They typically occur near the top of the groundwater table, likely representing oxidation-reduction (redox) interfaces associated with historic groundwater fluctuations. These zones are typically visibly enriched in iron oxides, most likely in the form of hematite ($Fe_2O_3$), formed under alternating oxic and anoxic conditions (Usman et al., 2021). Grey sand, on the other hand, is a less dominant facies and appears mainly in BH2 and BH4, which may represent localized transitional zones within the depositional environment. The grey coloration of the sand is likely attributed to the presence of iron-bearing minerals, minor clay or organic coatings on quartz grains or some heavy mineral fractions.

Figure 3 confirms the shallow position of the groundwater table at BH3. Although the figure does not depict water chemistry, previous hydrogeological studies in Brunei have shown that such shallow aquifers commonly contain elevated dissolved iron

(Azffri et al., 2023; Azhar et al., 2019). This iron-enrichment, if remobilized into the sand matrix, could pose a contamination risk that may affect optical clarity and purity which are key parameters in glass used for photovoltaic applications.

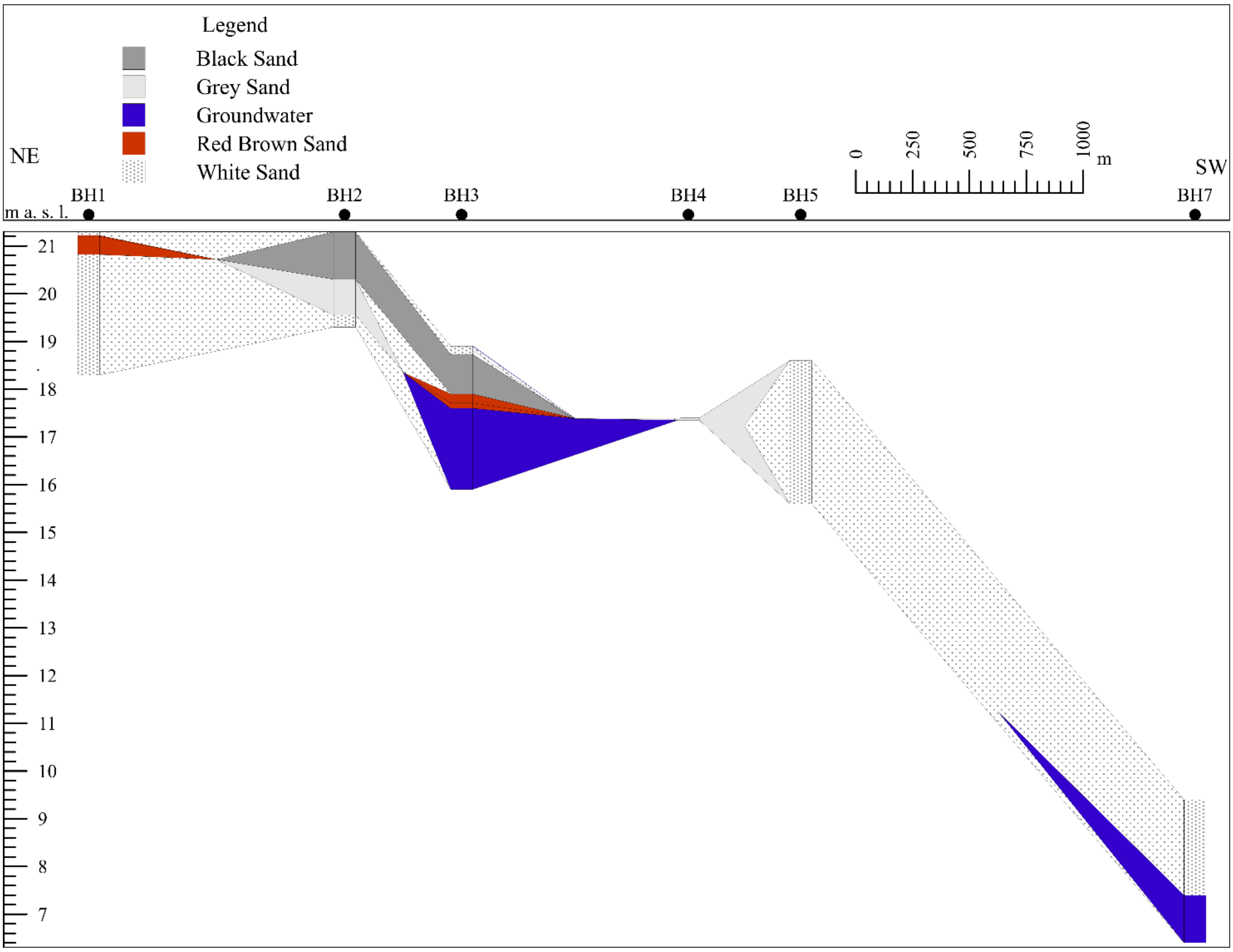


**Figure 2.** Geological cross section along the hand-augered boreholes

A spatial trend is also evident: towards the southeast (BH5-BH7), the deposit becomes more uniform, consisting almost entirely of clean white sand with minimal organic or iron-bearing material. These southeastern zones may be more suitable for industrial extraction, particularly where high silica purity is required for industrial or photovoltaic applications, where even trace impurities such as Fe, Ti, or organics can reduce solar transmittance and energy conversion efficiency.

To better understand the internal architecture and hydraulic behavior of the deposit, further hydrogeological or tracer-based investigations are recommended. Evaluating the connectivity between different facies and the role of low-permeability layers could help predict impurity and fines migration pathways, groundwater influence, and long-term quality consistency which are all critical for maintaining sand standards suitable for photovoltaic (PV)-grade glass (Gödeke et al., 2008; Gharbi et al., 2014; Sazali et al., 2018).

Overall, the lithological investigations confirm that the White Sands of Tutong exhibit greater heterogeneity than previously reported, with implications for both resource management and ecological preservation. Identifying zones of low impurity concentration, minimal redox alteration, and limited organic content will be key to maximizing the potential of the deposit as a strategic raw material for solar energy applications.


**Figure 3.** (a) Coring with auger (b) Surrounding environment at site 1 (c) Reflection of the groundwater table at borehole 3 (BH3)

### 3.2 Geochemical characterization and trace element analysis

Geochemical analysis via ICP-OES and ICP-MS revealed that the white sand fraction a appears to show a slight enrichment in titanium, with a concentration of 441 µg/g. The iron concentration was measured to be 200 µg/g. This is hardly surprising, given that titanium-bearing minerals such as rutile and ilmenite are highly resistant to chemical weathering (Goss and Oliver, 2023). However, the Spider diagram does not show an enrichment in Titanium (Figure 4). The graph shows a major negative Strontium anomaly, in line with intense chemical weathering and plagioclase removal. The overall flat REE pattern suggests intense leaching and silica rich material.

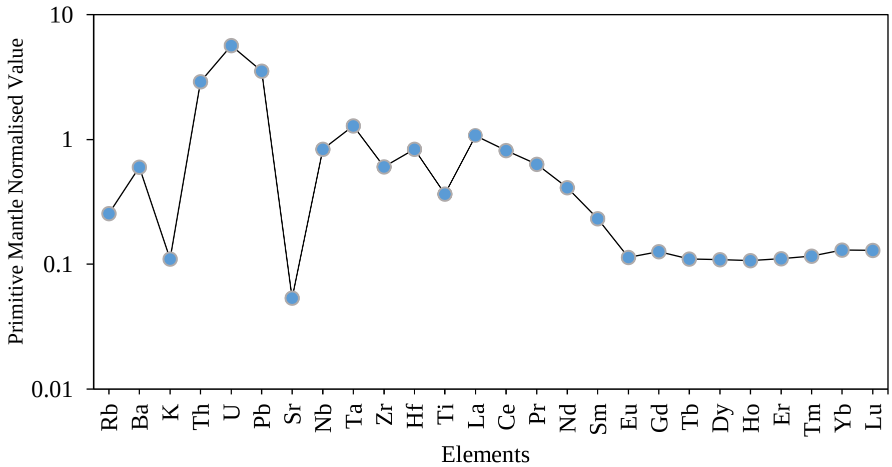


**Figure 4.** Spider Diagram, primitive mantle normalized, of silica sand sample

The rare earth element (REE) pattern graph, as shown in Figure 5, suggests a felsic provenance for the sand. A calculated La/Th ratio of 3.02 is consistent with derivation from the upper continental crust, which is characteristically silica rich. The cerium anomaly, close to 1, indicates no significant redox-related fractionation, while a negative europium anomaly implies feldspar depletion, typically resulting from prolonged chemical weathering.

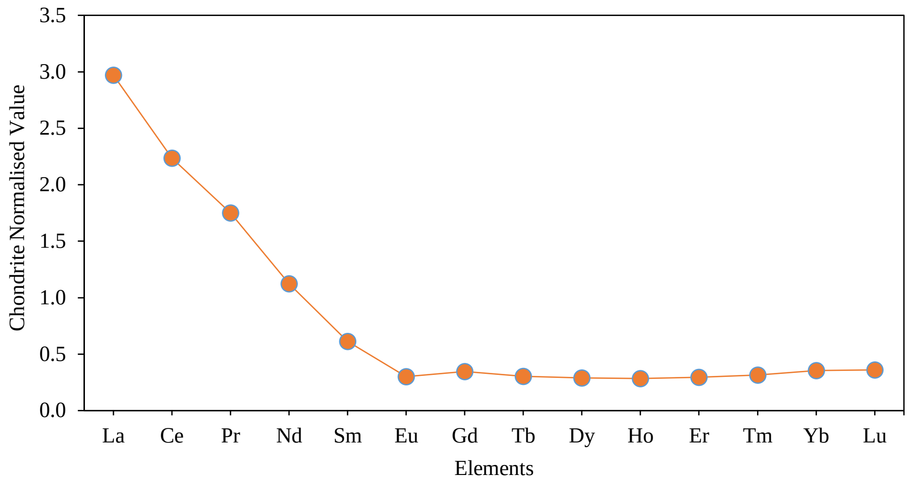


**Figure 5.** REE-pattern graph of silica sand sample, chondrite normalised

These signatures collectively reflect a chemically mature and recycled sediment, supporting the interpretation that the deposit originated from felsic rocks and was modified by prolonged weathering and reworking in a coastal dune environment (Götze and Lewis, 1994).

In addition, the REE pattern exhibits light REE (LREE) enrichment relative to heavy REEs (HREEs), consistent with felsic source rocks and further supporting an upper crustal origin. The lack of enrichment in transitional metals such as Cr, Co, and Sc suggests an absence of significant mafic or volcanic input. Moreover, the relatively flat HREE distribution and absence of anomalous spikes indicate minimal hydrothermal overprinting or heavy mineral contamination. Together, these features reinforce the interpretation of the White Sands of Tutong as a geochemically mature deposit with limited post-depositional alteration, underscoring its potential as a high-quality raw material for photovoltaic glass production.

Based on the favorable geochemical characteristics of the white sand, particularly its high silica content and low levels of impurities, the material was subsequently used to prepare glass melts for further evaluation.

### 3.3 Optical properties of the synthesized glass

The glass transition temperature was measured to be 549.5°C, which is within the expected range for soda-lime glass and indicates good thermal stability; this is a key requirement for photovoltaic application, which must withstand prolonged outdoor exposure and thermal cycling. The composition of the two prepared glass melts, measured by XRF, is summarized in Table 1, which confirms that both batches closely matched the target composition (74% $SiO_2$, 16% $Na_2O$, and 10% CaO). Transmittance measurements were made for Glass 1.

**Table 1.** Composition of two glass melts (Glass 1 and Glass 2) with Brunei silica sand

| Parameter | Glass 1 | | Glass 2 | |
|---|---|---|---|---|
| | Mass% | mol% | Mass% | mol% |
| $SiO_2$ | 75.38 | 75.7 | 75.37 | 75.4 |
| $Na_2O$ | 15.72 | 15.3 | 15.86 | 15.4 |
| CaO | 8.46 | 9.1 | 8.55 | 9.2 |
| $Fe_2O_3$ | 0.131 | 0.049 | N/A | N/A |
| Total | 99.69 | | 99.78 | |

The close agreement with standard soda-lime float glass compositions, commonly used in solar panels (Pilkington, 2025), demonstrates the chemical compatibility of the Tutong sand for photovoltaic glass production. The high $SiO_2$ content, sourced directly from the sand, is essential for achieving the optical transparency and thermal resistance required in PV applications. Moreover, the appropriate balance of $Na_2O$ and CaO contributes to the glass's workability, durability, and mechanical strength, all of which are vital for long-term outdoor performance.

However, minor bubbles and streaks were observed in the resulting glass samples (Figure 6), which may have resulted from incomplete melt refinement or temperature gradients during the melting and cooling phases. Despite their presence, these bubbles did not significantly affect the optical performance of the glass, as confirmed by subsequent transmittance measurements. Nevertheless, future melt refinement, such as the use of fining agents or optimized annealing protocols, could further reduce bubble content and enhance the optical quality, thereby improving its suitability for high-performance photovoltaic applications.

**Figure 6.** Molten glass sample (40×40×20 mm) from Brunei silica sand

The solar transmittance of the polished 3 mm glass slice was measured to be 90.2%, confirming its suitability for photovoltaic applications (Lim et al., 2021). As shown in Figure 7, the glass performs better than conventional float glass (solar transmission 87.2%) and is comparable to borosilicate glass (solar transmission 92.2%). Importantly, the glass maintains high transmissivity even at longer wavelengths, unlike float glass, which exhibits a notable decline. In comparison, commercial solar glass, typically a low-iron soda-lime-silicate glass of similar thickness, has a reported solar transmittance of approximately 90.3% (Pilkington, 2025), placing the glass well within the expected range for photovoltaic-grade materials.

The slightly lower solar transmittance than that of the borosilicate glass may be attributed to its elevated titanium concentration; titanium, particularly in the form of $TiO_2$, can reduce optical clarity at certain wavelengths (Albarzan et al., 2021). Despite the slightly lower transmittance compared to borosilicate glass, the glass presents several practical advantages for photovoltaic applications. Most notably, the glass is expected to be more cost-effective to produce, due to lower melting temperatures and reduced energy requirements. It also offers better thermal compatibility with other PV module components, which is essential for minimizing stress and degradation under fluctuating outdoor temperatures. In addition, its ease of fabrication, including cutting, polishing, and tempering, makes it highly suitable for industrial-scale production. Importantly, the glass closely aligns with standard float glass compositions (Pilkington, 2025), ensuring drop-in compatibility with existing PV manufacturing infrastructure. Finally, the use of locally sourced silica sand from Tutong enhances supply chain sustainability and supports national resource utilization. Together, these factors make the glass suitable for cost-effective photovoltaic applications. Anti-reflective coatings applied on the glass could further increase the solar transmittance. A study by Helsch and Deubener (2012) found that applying a pure porous silica coating increased the solar transmittance of a silica glass by 4.1%.

### 3.4 Implications for Brunei's silica sand development

The present investigation confirms that the White Sands of Tutong exhibit high silica purity and favorable optical properties for photovoltaic applications. These results are consistent with earlier exploration studies that highlighted the national significance of this deposit. Initial surveys in the commissioned by the Brunei Economic Development Board (BEDB) in 2012 delineated an estimated 46 million metric tonnes of silica sand in Tutong District, covering approximately 2,000 acres (BEDB, 2012). Within this reserve, a particularly high-grade zone was identified with approximately 14 million tonnes of sand exhibiting exceptional purity levels of 99.5-99.9% $SiO_2$ (BEDB, 2012). Such figures underscore the strategic importance of the deposit as one of the few documented silica resources in Brunei with characteristics that approach international benchmarks for advanced industrial applications.

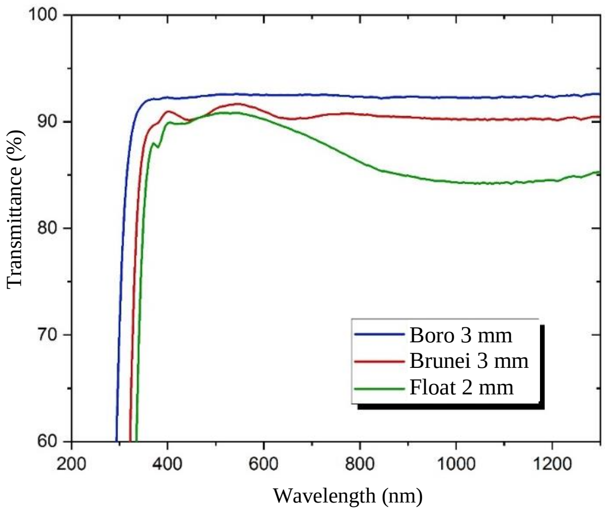


**Figure 7.** Transmittance of 3 mm thick Brunei glass sample compared with 2 mm standard float and 3 mm borosilicate glass

A spectrum of industrial uses emerges when considering both historical reserve estimates and the current laboratory-based analyses. Beyond photovoltaic glass, which this study has demonstrated to be technically feasible, Brunei's silica sand could serve multiple industries. These include glass manufacturing (from tableware and container glass to optical-grade products) (BS2975, 1988), silicon production for semiconductors and solar cells, fused silica for specialty optics, refractories and abrasives, foundry moulds, sodium silicate, and insulating fibres.

To realize this potential, attention must be given to beneficiation and processing requirements. The sand from Tutong, while already of high quality, will require classification, scrubbing, washing, flotation, and drying to consistently meet the stringent specifications for high-purity glass and photovoltaic silicon (>99.6-99.9% $SiO_2$, <0.02% $Fe_2O_3$) (Elsner, 2016; Vogt et al., 2016).

Looking forward, strategic partnerships with foreign investors or technology providers could facilitate the establishment of domestic glass and silicon processing plants, creating skilled employment opportunities and enabling technology transfer (Chowdhury et al., 2025). On the other hand, the ecological sensitivity of the White Sands of Tutong, home to a rare heath forest ecosystem (Din et al., 2015) and underlain by shallow aquifers (Azffri et al., 2022; Junaidi et al., 2025), requires rigorous environmental management. Any mining operation would necessitate comprehensive environmental impact assessments, water management strategies, and alignment with Brunei's National Climate Change Policy to ensure that development remains consistent with sustainability principles. Any potential resource extraction should allow for remediation work covering the same size as the affected area to protect the natural environment.

## 4. CONCLUSION

High-purity silica sand is an essential raw material for advanced technologies, particularly in the photovoltaic (PV), semiconductor, and optical industries. In the context of Brunei's national agenda to diversify its economy beyond fossil fuels, the availability of local strategic minerals such as quartz becomes increasingly important. The White Sands of Tutong, historically recognized for their visual distinctiveness, are among the few known silica deposits within the country, but yet, until now, limited modern assessments have been conducted to evaluate their industrial suitability and environmental constraints.

This study combined lithological investigations, via hand-augered boreholes, with laboratory-based geochemical and optical analyses to assess the composition and potential uses of the deposit. Subsurface profiling revealed that the sand body is more geologically complex than previously reported, with localized occurrences of red-brown and black sands that interrupt the continuity of the white sand layer. These facies appear associated with varying redox conditions, groundwater dynamics, and possible post-depositional alteration. The presence of a shallow water table and a rare tropical heath forest further emphasize the ecological sensitivity of the site. Geochemical analysis confirmed the sand's high silica content, with a slight enrichment in titanium attributed to the presence of resistant minerals such as rutile and ilmenite. Rare earth element (REE) ratios indicated a felsic provenance and advanced chemical maturity. Glass produced from the sand achieved a solar transmittance of 90.2%, outperforming conventional float glass and approaching the levels seen in borosilicate and commercial solar glass. These results show that the sand is suitable for PV applications.

The measured transmittance and chemical composition indicate that the Tutong sand meets key requirements for photovoltaic glass production. However, the ecological and hydrological sensitivities identified during the investigation warrant serious consideration. Any future development of this resource must balance economic potential with long-term environmental stewardship.

## ACKNOWLEDGEMENTS

The authors thank Universiti Brunei Darussalam for supporting this research. The authors thank Masa Institute, Germany, for the chemical analysis of the glass sample. The authors are grateful to Hj Muhd Nazmi Hilman Hj Suani for fieldwork. The authors are grateful for the analytical work of Nicole Nolte-Moser for this study. The authors thank Malcolm Anderson for his review of the manuscript. The authors are grateful to Dieter Gödeke for supporting this research.

## AUTHOR CONTRIBUTIONS

Conceptualization, SG, Methodology, SG, AA, AS, GH, NS, JD, EA Field Work NS, Formal Analysis: GH, JD, JW, NS, SG, AA, EA Project Supervision, SG, AA, EA, AS, Writing First Draft: SG, Writing Review and Editing, SG, AA, AS, JW, GH, NS, EA, JD.

## DECLARATION OF CONFLICT OF INTEREST

The authors declare no competing interests.

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