

# Can the Potential of Hong Kong Rocks be Harnessed for Effective Thermal Energy Storage?

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## ABSTRACT

Alternative clean energy sources such as solar, nuclear, and geothermal have undergone considerable advancements. Thermal energy storage (TES) can also be employed to directly capture and store waste heat generated from diesel generators' exhaust gases. TES can be classified into three primary categories: sensible heat storage, latent heat storage, and thermochemical heat storage. Sensible heat storage involves storing energy by raising the temperature of a material without changing its phase. No TES systems have been implemented in Hong Kong thus far. This study aims to assess the thermophysical properties of Hong Kong rocks, serving as a foundational reference for future TES site and material selection endeavors. A total of 15 common rock types were selected, comprehensively covering igneous, sedimentary, and metamorphic lithologies. These rock samples were tested for four physical or petrology and five thermophysical parameters under continuous real-time heating up to 1000 °C. Through multidimensional evaluation, the suitability of these rocks from Hong Kong to serve as thermal energy storage media was assessed. The results obtained indicated that Hong Kong basalt is the optimal candidate for high-temperature TES material, with 850°C identified as the suitable maximum working temperature. Other igneous rocks from Hong Kong can be utilized for mid-to-low temperature range (100–500 °C) TES engineering.

## 1 INTRODUCTION

With the continuous depletion of fossil energy resources and the escalating importance for environmental protection, alternative clean energy sources such as solar, nuclear, and geothermal have undergone considerable advancements. Specific low-carbon technologies, including concentrating solar power, have emerged to address this prevailing issue. However, the intermittency inherent in these energy sources poses a challenge to the security of energy supply. Consequently, energy storage has been identified as a viable solution for managing fluctuations and intermittencies in renewable energy sources. For instance, solar energy harvested during periods of sunlight can be utilized to provide heat or electricity during nighttime or peak demand periods. Thermal energy storage (TES) can also be employed to directly capture and store waste heat generated from diesel generators' exhaust gases.

TES can be classified into three primary categories: sensible heat storage, latent heat storage, and thermochemical heat storage (Park et al., 2014). The classification is based on the underlying mechanisms by which energy is stored and released. Sensible heat storage involves storing energy by raising the temperature of a material without changing its phase. Insulating materials are used around the storage medium to minimize heat loss to the surrounding environment. These insulation barriers can consist of natural materials, such as clay, or engineered solutions designed to limit thermal conductivity. Additionally, implementing heat exchangers optimizes heat transfer when needed while minimizing losses during storage. During the charging phase (heat input), the exchangers facilitate efficient heat transfer; during discharging, they help extract heat with minimal loss. There are a few studies on the suitability of various rocks for high-temperature packed-bed TES systems. Grirate et al. (2014) investigated the thermogravimetry and heat capacity changes of granite, basalt, quartzite,



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marble, and hornfels within the temperature range of 25 – 400 °C. They concluded that these rocks are good candidates for thermal energy storage by sensible heat up to 350 °C (Grirate et al., 2014). Tiskatine et al. (2016) examined the changes in Vickers hardness and porosity of limestone, granite, rhyolite, and marble from Morocco when heated between 20 °C and 650 °C. They found that rhyolite showed excellent potential for high-temperature TES (Tiskatine et al., 2016). Becattini et al. (2017) selected six types of rocks of Alpine origin, and tested the changes in specific heat capacity, porosity, and degree of cracking under temperatures ranging from 100 to 600 °C. They concluded that thermal treatment led to decreases in specific heat capacity and increases in porosity (Becattini et al., 2017).

The principle of localization holds significant importance in terms of both economic considerations and practical convenience. Besides, Allen et al. (2014) emphasize the necessity for site-specific studies of rock properties (Allen et al., 2014). In Hong Kong, there is an increasing government-led initiative toward adopting clean energy practices, making large concentrated solar power stations a feasible option. Additionally, data center operations typically produce large amounts of waste heat, presenting a considerable potential for the application of sensible heat storage in the region. However, to date, no TES systems have been implemented in Hong Kong thus far, and systematic research on the thermophysical properties of common rocks in the region remains limited. This study aims to identify typical and prevalent rock types and assess their thermophysical properties, serving as a foundational reference for future TES sites and material selection endeavors. In this work, a total of 15 common rock types were selected, comprehensively covering igneous, sedimentary, and metamorphic lithologies. These rock samples were tested for four physical or petrology tests (density, P-wave velocity, X-ray diffraction, and X-ray Fluorescence) and five thermophysical parameters (thermogravimetry, thermal expansion coefficient, heat capacity, thermal diffusivity, and thermal conductivity) under continuous real-time heating up to 1000 °C, a temperature that is sufficiently high for most TES systems. Besides, in the characterization process, the heterogeneity and anisotropy of typical rock types were considered and analyzed. To the best of our knowledge, this study provides a relatively comprehensive characterization of rocks for sensible thermal energy storage medium, making it a valuable reference for future research in the field. Additionally, the thermal properties of rocks are crucial considerations for environmentally sensitive projects such as the design and installation of buried high-voltage power cables and oil and gas pipelines. The findings of this study are beneficial not only for selecting appropriate rock types for TES medium but also for current and prospective high-temperature rock engineering endeavors in Hong Kong and the world.

## 2 Materials and methods

### 2.1 Sample preparation

Fifteen rock types (Table 1) were selected based on their prevalence and representativeness in the geological makeup of Hong Kong. Encompassing granitic, volcanic, sedimentary, and metamorphic varieties, these chosen rocks collectively offer a representative overview of the geological diversity found within Hong Kong. Besides, to consider the effects of heterogeneity or rocks, we collected rocks with different mineral grain sizes, such as fine-grained, medium-grained, and coarse-grained granite, metasiltstone, and fine metasandstone. The fine metasandstone and metasandstone have the same mineral composition (slightly different mineral proportion), but their grain size and texture appear slightly different. Their differences are likely due to different depositional environment and metamorphism histories, which we believe may affect their thermodynamic properties.

Table 1: General properties of testing rock samples

No.	Rock type	Acronym	Weathering degree	Sampling location	Density (kg/cm <sup>3</sup> )	$V_p$ (km/s)
1	Fine-grained Granite	GF	Fresh	Braemar Hill, North Point	2587	3.935
2	Medium-grained Granite	GM	Fresh	Elevated Road, Kai Yuen Street, North Point	2593	4.300
3	Coarse-grained Granite	GC	Fresh	Black Point, Tuen Mun West, New Territories	2616	5.063
4	Granodiorite	GD	Fresh	Tai Po	2648	4.900
5	Tuff-Tai Mo Shan Formation	TT	SD	Tai Mo Shan	2589	5.000
6	Tuff-High Island Formation	TH	SD	East Dam	2604	5.441
7	Basalt	BS	SD	Cheung Chau Ferry Pier	2742	5.568
8	Feldsparphyric rhyodacite	FRD	Fresh	Cheung Chau Ferry Pier	2631	5.833
9	Feldsparphyric rhyolite	FRL	Fresh	North Lantau	2722	6.279
10	Marble	MB	Fresh	Yuen Long	2703	5.909

11	Metasandstone	MSD	SD	Ma Cho Lung	2543	2.016
12	Sandstone	SD	Fresh	Kong Nga Po Road and Ping Che Road	2687	4.868
13	Siltstone	ST	Fresh	Sandy Ridge Cemetery, Sandy Ridge	2724	5.214
14	Metasiltstone	MST	SD	Tai O	2683	4.904
15	Fine Metasandstone	FMSD	SD	Tai O	2684	5.263

## 2.2 Characterization techniques

XRD analyses were conducted using a Rigaku MiniFlex 600 powder X-ray diffractometer (Rigaku, Tokyo, Japan) equipped with Cu K $\alpha$  radiation. Thermogravimetric analysis (TGA) was conducted using a TGA 55 instrument (TA Instruments, New Castle, DE, USA) to determine the weight loss of the samples at elevated temperatures. The analysis involved heating the samples from room temperature (25 °C) to 1000 °C at a rate of 10 °C/min under a nitrogen atmosphere. The Laser Flash Analysis (LFA) technique, performed using the Netzsch LFA 427 instrument, was employed to determine the thermal diffusivity of the samples. Subsequently, thermal conductivity is computed based on thermal diffusivity. The thermal conductivity ( $k$ ) of the rocks under investigation was determined by multiplying their density ( $\rho$ ), specific heat capacity ( $C_p$ ), and thermal diffusivity ( $\lambda$ ) as a function of temperature ( $T$ ) (Nahhas et al., 2019). The specific heat capacity was determined using a comparison method with sapphire serving as the calibration standard. The linear thermal expansion of Hong Kong rocks was assessed to establish the suitable maximum operational temperature. This evaluation utilized the NETZSCH DIL 402 Expedit Supreme pushrod dilatometer, heating samples to 1000 °C at a rate of 2.5 °C/min.

## 3 Results

### 3.1 Mineralogical compositions

Table 2 presents the mineralogical compositions of the tested rocks. Quartz minerals are prevalent in nearly all the examined samples. Metasandstone, fine metasandstone, and metasiltstone consist primarily of muscovite (a hydrated mineral from the mica group) and quartz. Quartz is renowned for its high thermal conductivity, 7.7 W/m·°C. This property facilitates thermal stratification within the bed and accelerates the rate of heating and cooling during thermal cycling. Additionally, rocks abundant in quartz are known for their hardness (Özkahraman et al., 2004) and tend to exhibit higher thermal conductivities at room temperature (Allen et al., 2014).

On the other hand, the high quartz content could lead to the degradation of rocks abundant in this mineral, such as metasandstones and metasiltstones, during thermal cycling. The anisotropic expansion of quartz during its  $\alpha$ - $\beta$  phase transition at 573 °C significantly compromises the integrity of granite samples (Chaki et al., 2008). Additionally, Allen et al. (2014) and Tiskatine et al. (2016) demonstrated that rocks with elevated quartz content are ill-suited for thermal cycling at high temperatures due to the disparate expansion rates of quartz (Allen et al., 2014), which exhibits a substantially larger volumetric coefficient of expansion compared to other minerals, thereby predisposing them to cracking and disintegration (Tiskatine et al., 2016). However, it has also been noted that the mechanical strength of rocks typically increases with quartz content (Allen et al., 2014). Therefore, rocks containing quartz as a binding agent may be better suited for the lower and middle sections of the storage facility, where temperatures are lower and greater mechanical resilience is required.

Marble, consisting predominantly of calcite, is characterized by interlocking calcium carbonate crystals, resulting from the metamorphism of limestone subjected to heat and pressure. Additionally, Fredrich and Wong (1986) observe that in calcitic rocks, the unusual thermal expansion anisotropy of calcite can induce thermal cracking, suggesting that these rocks may undergo permanent alterations prior to the onset of calcination reactions (Fredrich and Wong, 1986).

Table 2: Mineralogical compositions of the rocks

Mineralogical composition (vol%)	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Fine-grained Granite	19.36	66.62		6.45	6.57											
Medium-grained Granite	20.62	72.98		5.41												
Coarse-grained Granite	36.53	51.77	10.70													
Granodiorite	29.07	31.49	7.18	31.26												
Tuff-Tai Mo Shan Formation	29.20						30.46	39.35								
Tuff-High Island Formation	21.34	46.85		4.46		20.48			5.88							
Basalt	18.8	29.8		46.6	3.8											
Feldsparphyric rhyodacite	10.17	45.97								1.05	32.90	8.91				
Feldsparphyric rhyolite	11.3	33.9			6.9								46.9			
Marble														99.00		
Metasandstone	65.63															33.37
Sandstone	21.85	45.45			9.13											22.57
Siltstone	19.27				36.53											43.21
Metasiltstone	63.36															35.64
Fine Metasandstone	72.40															26.60

Notes: A-Quartz; B-Albite; C-Biotite; D-Anorthite; E-Clinocllore; F-Microline; G-Berlinite; H-Graphite; I-Orthoclase; J-Sodalite; K-Micropertthite; L-Epidote; M-Microcline; N-Calcite; O-Muscovite; P-Pargasite

### 3.2 Thermogravimetric Analysis

Thermal stability analysis holds significant importance in evaluating the resistance of TES materials to high temperatures. TGA curves illustrate the mass loss of the sample as a function of temperature during thermal degradation. The differentiation of the TGA curve results in the Derivative Thermogravimetric (DTG) curve, which provides insights into the relationship between the rate of mass change of the sample and temperature. Figure 1 illustrates the relationship between sample weight and temperature. TGA was utilized to estimate the total volatile content within the rocks, including carbon dioxide and water. The findings suggest that most of the rocks exhibit minimal organic matter and consequently experience limited weight loss during heating. Notably, all samples displayed weight loss occurring in three distinct stages.

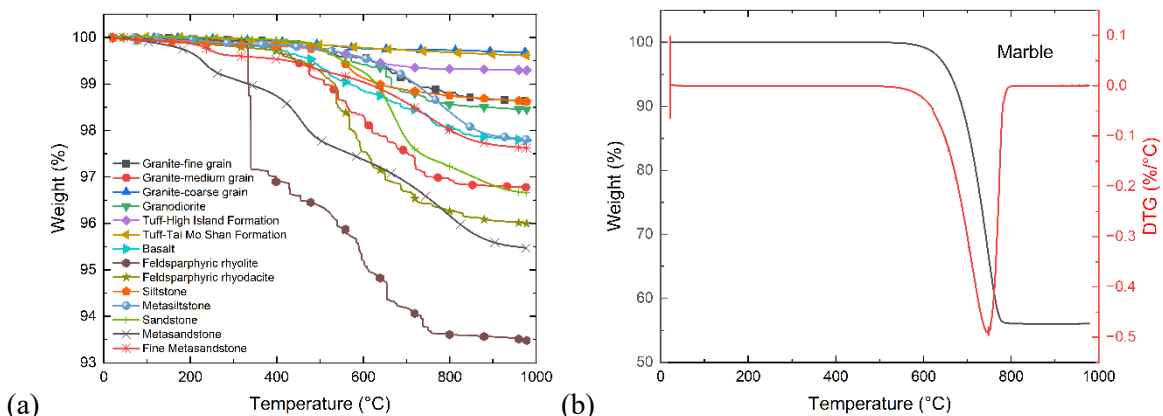


Figure 1: Thermogravimetric analysis curves of major Hong Kong rocks. (a) most rock types except marble; (b) marble

The initial stage occurs from room temperature up to approximately 300 °C, with minimal mass variation observed. Within this temperature range, the weight loss is approximately 1% for metasandstone and nearly 0.5% for fine metasandstone, while for other samples, the weight loss is negligible. In this stage, weight loss in most rocks can be attributed to the evaporation of absorbed water and bonded water. During the second stage (300 – 800 °C), the rate of mass loss escalates and varies among different rock types. Within this temperature range, weight loss primarily arises from mineral decomposition, notably clay minerals. For most rocks, beyond 550 °C, all the tested rock samples exhibit oxidation of organic matter, contributing to the increased mass loss observed in the TGA curve. In addition, the mass loss at temperatures up to 600 °C can be attributed to the dehydration phenomenon due to water evaporation and the decomposition of hydrated minerals containing hydroxyl bonds that broke at high temperatures, such as muscovite and biotite, as observed in the petrographic examination at temperature up to 760 °C (Hrifech et al., 2020). In the third stage (800 – 1000 °C), the mass loss gradually approaches a stable state. For most rocks, including carbonates, those containing clay minerals, or hydrates, significant reactions such as dehydration, dehydroxylation (i.e., the removal of water from hydroxyl compounds), and decomposition of carbonates typically conclude by 800 °C.

Overall, within a moderate temperature range of 100 °C to 300 °C, all examined rocks exhibit minimal mass loss, measuring less than 1%. Thus, they can be deemed thermally stable within this temperature range. In summary, the moderate temperature range (100 to 300 °C) effectively prevents the transformation of mineral phases, such as calcite and quartz, thereby ensuring the thermal stability of the rocks. Consequently, rocks like marble, granite, and sandstone, which are typically unsuitable for high-temperature applications due to transformations in calcite and quartz, demonstrate potential as energy storage materials for moderate temperatures (Hrifech et al., 2020; Mugi et al., 2022; Li et al., 2024). Conversely, mafic rocks such as basalt, along with felsic rocks like granodiorite and feldsparphyric rhyodacite, are identified as suitable candidates for high-temperature thermal energy storage at this stage.

### *3.3 Thermal expansion coefficient*

To determine the appropriate maximum working temperature for rocks in Hong Kong, thermal expansion coefficient measurements were conducted to evaluate the temperature range within which the material can be utilized without significant alteration of its mechanical properties. For the labels of anisotropic rocks, "/" denotes that the direction of heat source aligns with the bedding direction of the rock sample, while "⊥" indicates a perpendicular orientation. Figure 2 illustrates that granites, tuff-High Island Formation, tuff-Tai Mo Shan Formation, feldsparphyric rhyodacite, and sedimentary rocks exhibit a notable increase in thermal expansion around 573 °C. This phenomenon is attributed to the presence of quartz minerals, which undergo a 5% volume expansion as a result of the  $\alpha$ - $\beta$  phase transition (Chen et al., 2017). Hence, the maximum temperature at which these rocks can effectively store energy should not exceed 550 °C, to mitigate the substantial volume changes that occur during the cyclic heating-cooling processes encountered during their service life. Granodiorites (Figure 2b) experience a surge in thermal expansion at around 656 °C, which may be due to their high feldspar content compared to their low quartz content, in addition to the high content of total iron oxide that is represented by a high content of normative mafic minerals (Rashwan et al., 2023).

Basalt exhibits a relatively gradual increase in thermal expansion behavior from room temperature up to 850 °C. No significant discontinuities are observed in the expansion behavior throughout the entire temperature range from room temperature up to 850 °C, indicating stability. This stability aligns with the high-temperature origins of basalt rocks, suggesting they are already stabilized at this temperature range.

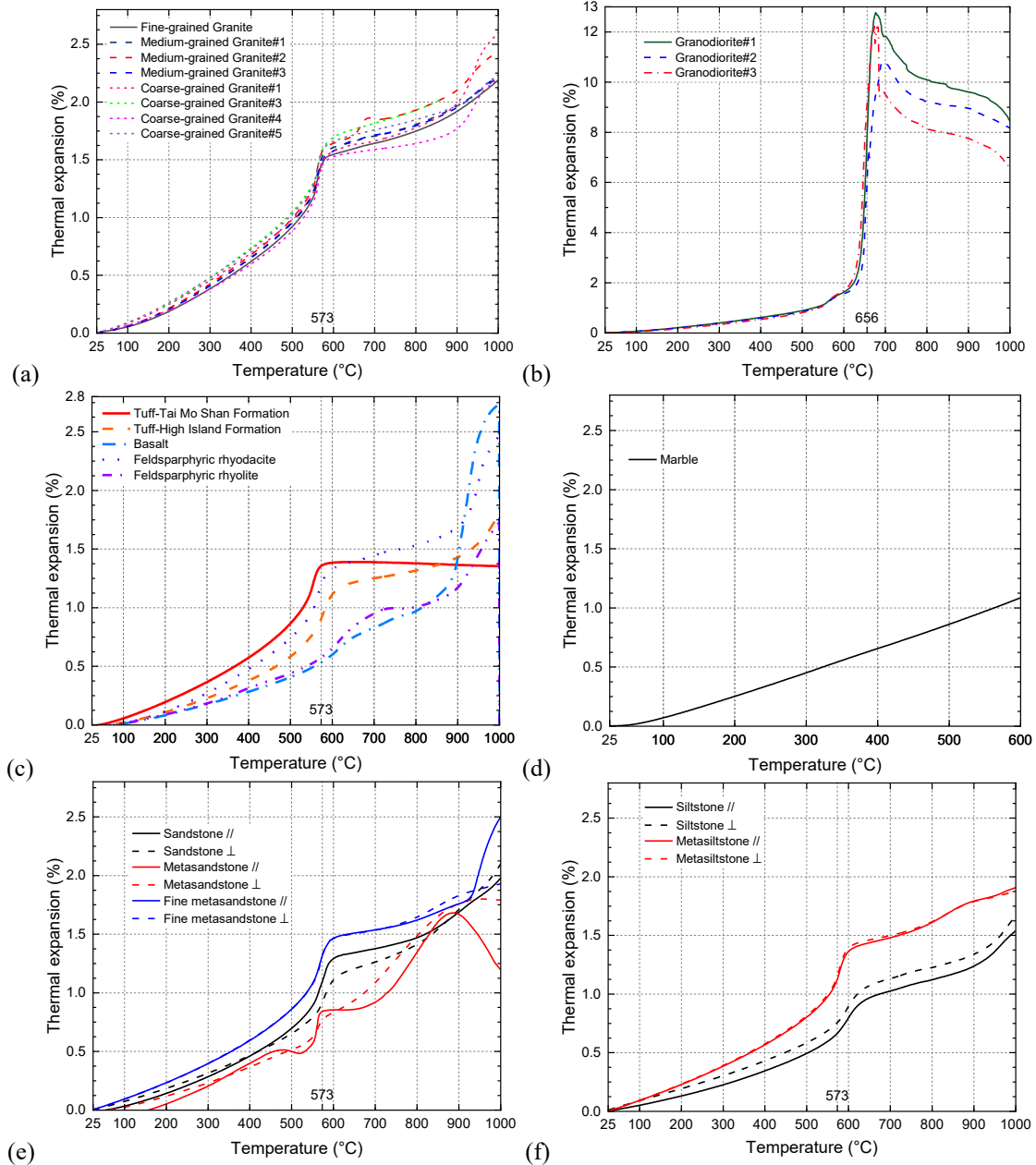


Figure 2: Thermal expansion of Hong Kong rocks. (a) Granites; (b) Granodiorites; (c) Other igneous rocks; (d) Marble; (e) Sandstones; (f) Siltstones

### 3.4 Heat capacity

The characterization of heat capacity is essential when selecting a sensible heat storage material because an increase in this property enhances the energy stored and reduces the volume of material required, thereby making the storage system more cost-effective. For all these tested samples, the specific heat capacity increases significantly with temperature. In the higher temperature range (700 - 1000 °C), the thermal expansion values gradually converge. This behavior aligns with the Dulong-Petit law, indicating that the heat capacity of solids reaches a constant value at high temperatures (Sutera and Skalak, 1993).

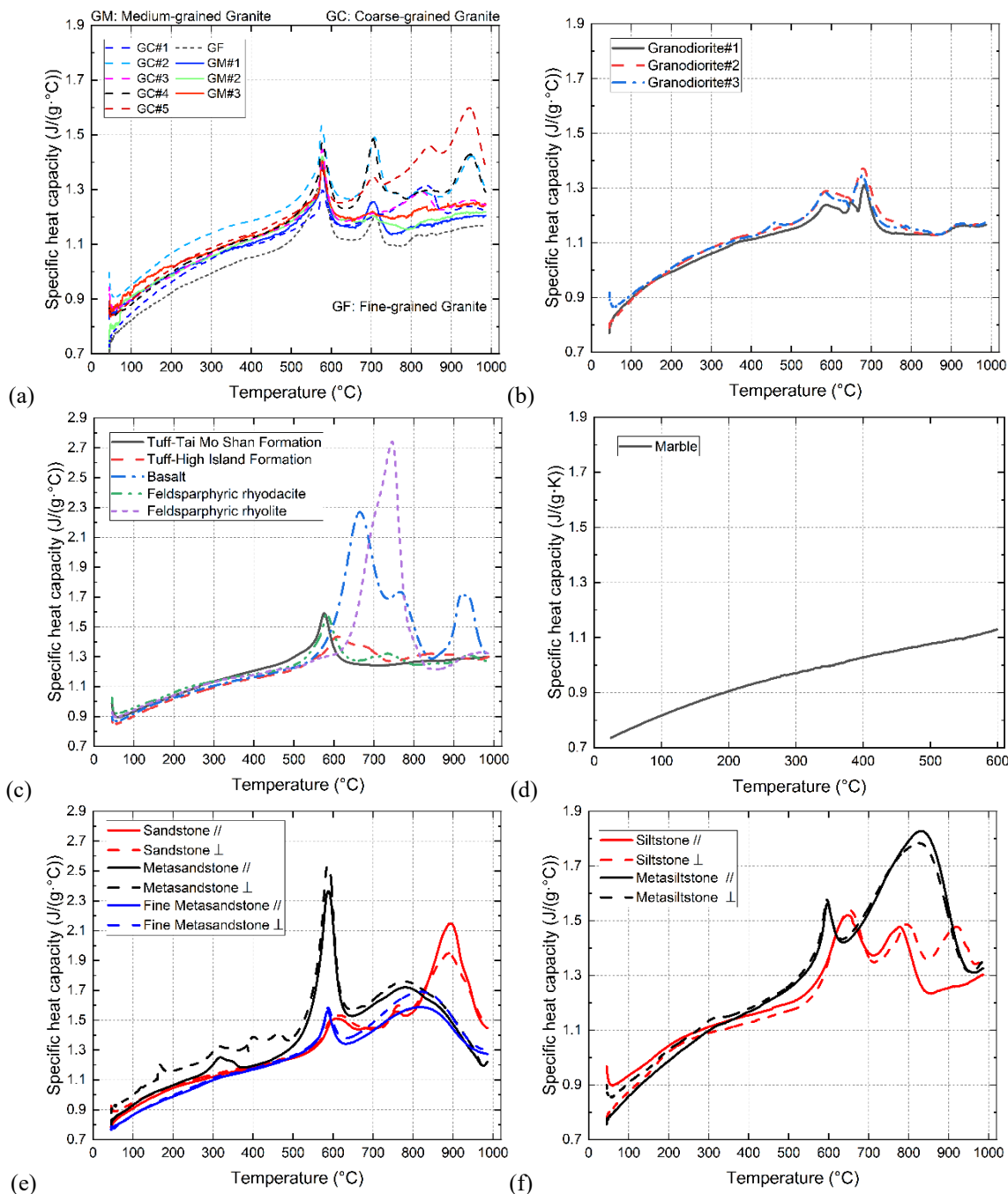


Figure 3: Specific heat capacity of Hong Kong rocks. (a) Granites; (b) Granodiorites; (c) Other igneous rocks; (d) Marble (600 °C); (e) Sandstones; (f) Siltstones

Among igneous rocks, basalt (Figure 3c) notably exhibits relatively high specific heat capacity values, particularly within the temperature range of 600-800 °C. Some minerals in basalt, such as chlorite and clinocllore, may undergo dehydration reactions at around 650 °C (Steudel et al., 2016). The dehydration process requires a large amount of heat absorption, resulting in spikes in the specific heat capacity curve. In granites, multi-peaks can be observed in the specific heat capacity curve. The first peak is associated with the quartz  $\alpha$ - $\beta$ -transition at 573 °C. The second peak, around 700 °C, may result from the decomposition and dehydration of biotite (Hrifech et al., 2020).

The specific heat capacity of the marble sample (Figure 3d) demonstrated a linear increase from 0.74 J/(g·°C) at room temperature to 1.13 J/(g·°C) at 600 °C. Previous research by Vosteen et al. (2003) has reported that sedimentary rocks, such as sandstone and siltstone, generally exhibit higher specific heat capacities compared to metamorphic rocks like marble (Vosteen and Schellschmidt, 2003). Our experimental findings validate this trend.

### 3.5 Thermal diffusivity and conductivity

Thermal diffusivity, along with the derived thermal conductivity, plays a crucial role in determining the rate at which heat can be released and extracted (Gil et al., 2010). During the discharge phase, rocks can transfer the energy accumulated to the heat transfer fluid (HTF). Optimal material for storage should possess high thermal diffusivity/conductivity, enhancing transient heat transfer and consequently reducing the duration of charging and discharging processes.

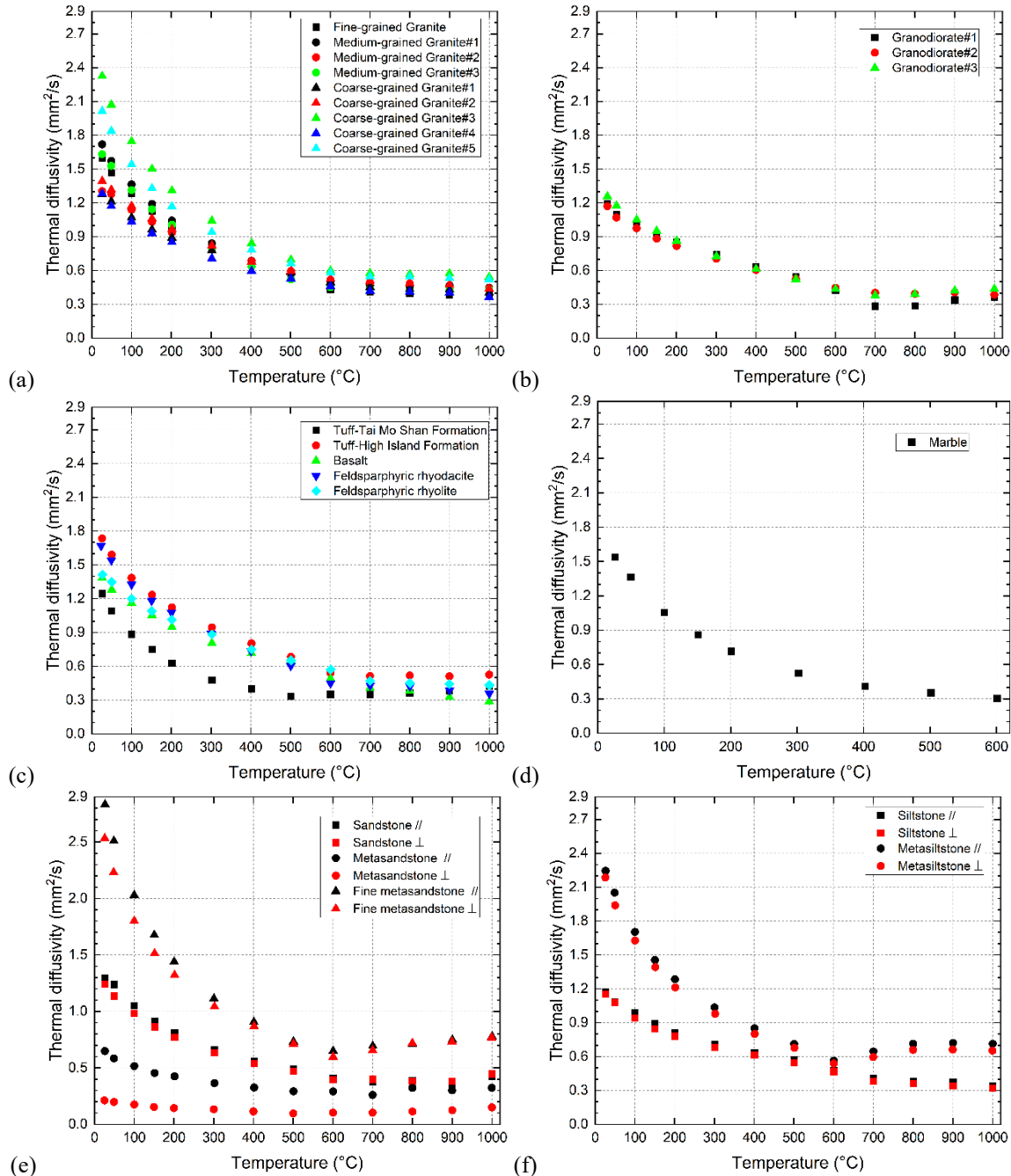


Figure 4: Thermal diffusivity of Hong Kong rocks. (a) Granites; (b) Granodiorites; (c) Other igneous rocks; (d) Marble (600 °C); (e) Sandstones; (f) Siltstones

Overall, there is an exponential decrease in thermal diffusivity across the temperature range of 25 to 1000 °C. At elevated temperatures, approximately 600 °C, thermal conductivity tends towards constant values. Among the tested igneous rocks, granites (Figure 4a), tuff-High Island Formation (Figure 4c), and feldsparphyric rhyodacite (Figure 4c) exhibit the highest thermal diffusivities, while basalt and feldsparphyric

rhyolite in Figure 4c fall into the intermediate range. In igneous rocks, thermal diffusivity correlates with quartz and feldspar content, with higher feldspar content (a poor conductor) associated with reduced diffusivity, and higher quartz content associated with higher thermal diffusivities. Despite calcite's superior heat conductivity compared to feldspars, rocks with high calcite content, such as marble (Figure 4d), exhibit low thermal diffusivities due to the absence of quartz. (Hanley et al., 1978).

Thermal conductivity stands as a pivotal criterion in identifying the optimal storage materials (Ismail and Stuginsky Jr, 1999). Theoretical calculations of thermal conductivity were conducted based on thermal diffusivity and heat capacity data (Figure 5).

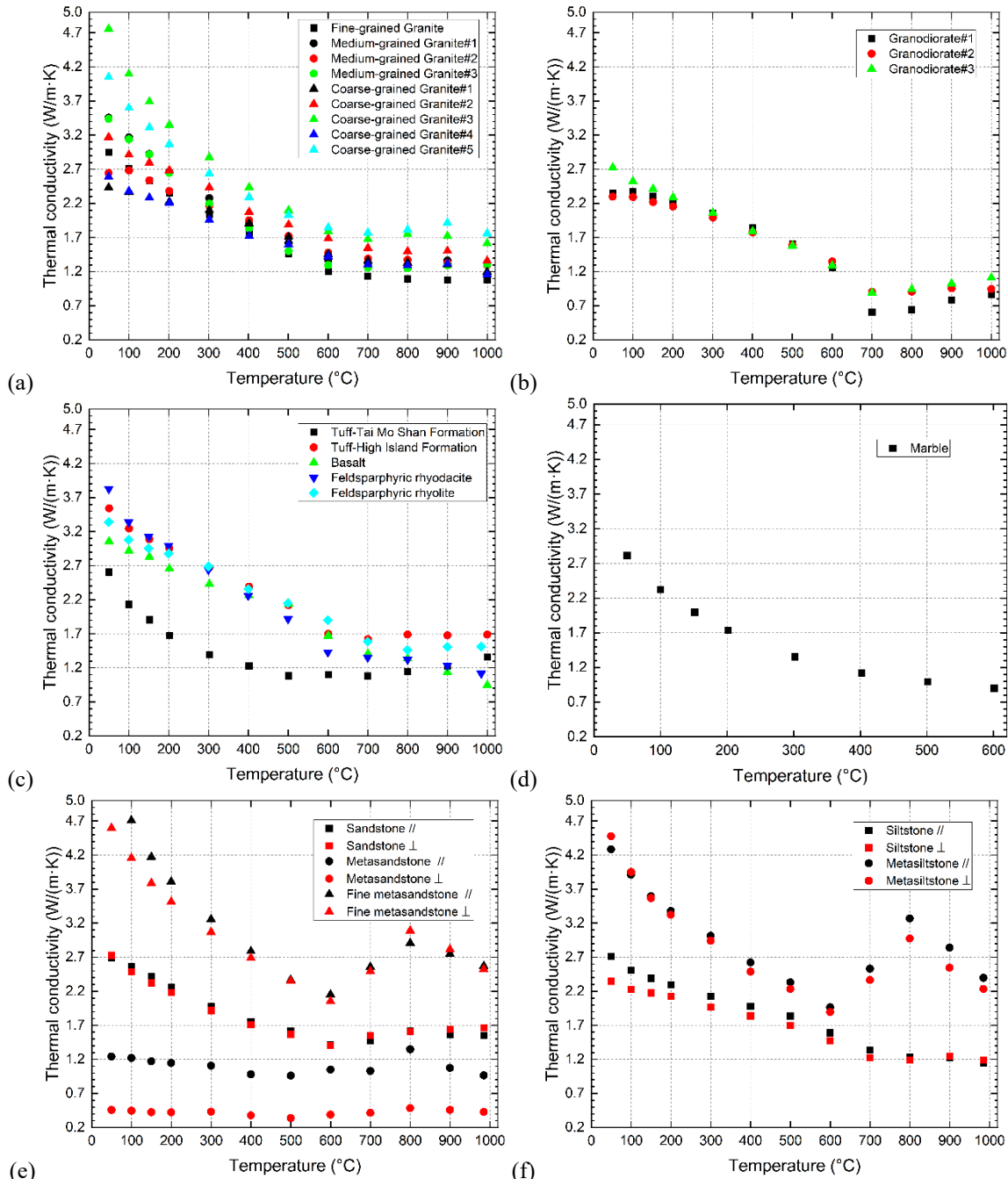


Figure 5: Thermal conductivity of Hong Kong rocks. (a) Granites; (b) Granodiorites; (c) Other igneous rocks; (d) Marble; (e) Sandstones; (f) Siltstones

Generally, the thermal conductivity of crystalline rocks decreases as temperature rises, unlike amorphous materials, which exhibit an increase in thermal conductivity with temperature. This phenomenon can be attributed to the reduction in the mean free path of phonons as temperature increases (Hu et al., 2017). Moreover,

rocks with higher initial thermal conductivity experience a more pronounced decrease as temperature increases (Labus and Labus, 2018). The integrity of the rock diminishes as microcracks and micropores develop, impeding the heat transfer process (Liu and Wong, 2024).

The examined rocks exhibit relatively high thermal conductivities when compared to other solid sensible heat storage materials. Specifically, the analyzed basalts demonstrate elevated thermal conductivity values at high temperatures in contrast to concrete. For instance, at 200 °C, concrete exhibits a thermal conductivity of 1 W/m·°C, whereas basalts (Figure 5c) display higher values, reaching 1.1 W/m·°C at 332.5 °C. Additionally, basalts significantly outperform molten salts in terms of thermal conductivity. Molten salts, on average, exhibit a thermal conductivity of 0.52 W/m·°C within the temperature range of 265–565 °C (Herrmann and Kearney, 2002; Tamme et al., 2005; Meffre, 2013; Bouvry et al., 2017).

#### 4 Discussion

The conducted tests provide a comprehensive evaluation of various major rock types in Hong Kong as potential candidates for sensible TES based on experimental data. The assessment criteria for an ideal high-temperature TES medium encompass several aspects, each associated with specific parameters: 1. Durability (Strength); 2. Thermal stability (TGA); 3. Energy density (Specific heat capacity); 4. Efficiency (Thermal diffusivity /conductivity); 5. Availability (Distribution density).

Developing an evaluation function can be intuitive for selecting the optimal TES medium. Overall, the five aspects (durability, thermal stability, energy density, efficiency, and availability) must have varying degrees of importance according to different situations. Here, for simplicity and universality, we have assigned them equal weight. The three levels of suitability (optimal, average, poor) can be quantified as scores 3, 2, and 1. Then, a basic evaluation function can be expressed below:

$$\begin{cases} S = w_D s_D + w_T s_T + w_E s_E + w_{EF} s_{EF} + w_A s_A \\ w_D + w_T + w_E + w_{EF} + w_A = 1 \\ w_D, w_T, w_E, w_{EF}, w_A \in [0,1] \end{cases} \quad (1)$$

where,  $s_D$ ,  $s_T$ ,  $s_E$ ,  $s_{EF}$ , and  $s_A$  are the scores of suitability in terms of durability, thermal stability, energy density, efficiency, and availability, respectively.  $w_D$ ,  $w_T$ ,  $w_E$ ,  $w_{EF}$ , and  $w_A$  are the weights of durability, thermal stability, energy density, efficiency, and availability, respectively.

Figure 6 provides a preliminary overall evaluation of Hong Kong rocks' suitability for TES medium. Among all the 15 rocks, basalt possesses the highest total score, followed by coarse-grained granite and feldsparphyric rhyolite, making these three types of optimal candidates. According to the 50-30-20 budget rule, we select the top 20%, i.e. 3, of the total rock types as the optimal, and determine 2.4 as the threshold score. It should be noted that, in this case, the weights of the five assessment factors are equal. In a specific TES system engineering, the weights can be determined according to an expert grading system or other methods, which warrants further site-specific research.

Rock type	Assessment factors					Total score $S$
	Durability $w_D = 0.2$	Thermal stability $w_T = 0.2$	Energy density $w_E = 0.2$	Efficiency $w_{EF} = 0.2$	Availability $w_A = 0.2$	
Fine-grained Granite	3	2	1	2	3	2.2
Medium-grained Granite	3	2	1	2	3	2.2
Coarse-grained Granite	3	2	1	3	3	2.4
Granodiorite	3	1	1	1	3	1.8
Tuff-Tai Mo Shan Formation	1	3	2	1	2	1.8
Tuff-High Island Formation	1	3	2	3	2	2.2
Basalt	3	3	3	2	2	2.6
Feldsparphyric rhyodacite	3	2	2	3	2	2.4
Feldsparphyric rhyolite	3	1	3	2	2	2.2
Marble	2	1	1	2	1	1.4
Metasandstone	2	1	2	1	1	1.4
Sandstone	1	2	2	2	1	1.6
Siltstone	1	2	2	1	1	1.4
Metasiltstone	2	2	1	3	1	1.8
Fine metasandstone	2	2	2	3	1	2.0

Notes: Green = Optimal (3); Yellow = Average (2); Red = Poor (1)

Figure 6: Evaluation of fifteen Hong Kong rocks over multiple assessment factors

Several igneous rock types, including granite, granodiorite, tuff-Tai Mo Shan Formation, tuff-High Island Formation, and feldsparphyric rhyodacite, exhibit a noticeable increase in thermal expansion at 573°C due to the quartz phase transition. This characteristic poses a significant risk to long-term **durability** as the cyclic expansion and shrinkage induced by heating and loading will generate numerous microcracks, compromising material strength. Additionally, the increased porosity can lower thermal diffusivity/conductivity, impacting the **efficiency** of these rocks as TES medium. Consequently, these igneous rocks are deemed unsuitable for exposure to temperatures exceeding 573 °C. However, some scholars propose their potential use in mid-low temperature range (100–500 °C) TES engineering (Tiskatine et al., 2017; Hrifech et al., 2020; Mugi et al., 2022). Besides, some of them still have other weaknesses. For example, granites contain a considerable proportion of hydrous minerals (e.g., biotite), which are not **stable** under hydrothermal conditions and alter to numerous minerals. Feldsparphyric rhyolite exhibits significant mass loss starting from 300 °C, indicating inadequate **thermal stability**. Granodiorites and tuff-Tai Mo Shan Formation exhibit low thermal diffusivity and conductivity, which could decrease the **efficiency** of the charging and discharging processes in TES engineering.

Basalt exhibits relatively high volumetric heat capacity and thermal diffusivity/conductivity, particularly at elevated temperatures ranging from 600 to 800 °C. It demonstrates stable thermal dilation behavior and the lowest thermal expansion coefficient recorded at 850 °C (0.011/°C), accompanied by negligible mass loss up to 1000 °C. Therefore, basalt appears to be well-suited for applications within this temperature range, or even higher, following thermal treatment. Experimental investigations indicate that basalt did not manifest any macroscopically visible damage after undergoing multiple thermal cycles (Geiger, 1984). The findings indicate that basalt stands out as the most suitable candidate for high-temperature TES material, meeting the required performance criteria for storage materials. This assertion is corroborated by previous studies (Grirate et al., 2016; Becattini et al., 2017; Nahhas et al., 2019). It is important to note, however, that basalt is not compatible with thermal oil, making it more suitable for alternative HTFs such as air (Grirate et al., 2016).

Solar tower systems can reach operating temperatures up to 600 °C, while conventional nuclear plants typically produce waste heat around 300 °C. Microsoft's Project Natick, an underwater data center, features cooling systems that efficiently manage heat, often exceeding 50 °C in some areas. Based on this analysis, if Hong Kong plans to build a TES system for different purposes, different rock types can be chosen according to their optimal operating temperature ranges.

## 5 Conclusions

The prosperity of Hong Kong's economy is accompanied by significant energy consumption. To alleviate potential future energy shortages, the development of clean energy and energy storage projects will be imperative. In this study, we examine the potential of fifteen rock types found in Hong Kong to serve as environmentally friendly and cost-effective materials for solid sensible thermal energy storage systems. Thermo-physical and mechanical properties of the selected Hong Kong rocks were analyzed, alongside their chemical and structural compositions. A comprehensive evaluation was conducted to assess the suitability of these rocks for thermal energy storage applications. Based on our findings, the following conclusions can be drawn:

- Thermogravimetric analysis revealed significant mass losses in marble and feldsparphyric rhyolite, necessitating their exclusion from the list of candidates under study to prevent any potential damage during thermal energy storage operations.
- Thermal dilatometry tests reveal that the majority of selected rocks in Hong Kong undergo a notable increase in thermal expansion around 573 °C due to the  $\alpha$ - $\beta$  phase transition of quartz. Granodiorite exhibits a distinctive surge in thermal expansion around 650 °C followed by a rapid decrease. Marble demonstrates a sudden decrease in expansion at 600 °C.
- Sandstone and siltstone exhibit high heat capacities, although they may fluctuate at elevated temperatures. Among the igneous rocks sampled in Hong Kong, basalt and feldsparphyric rhyodacite demonstrate relatively high heat capacities. Marble, on the other hand, exhibits the lowest but consistent heat capacity compared to all tested rocks.
- Fine metasandstone, metasilstone, granites, tuff-High Island Formation, and feldsparphyric rhyodacite exhibited the highest thermal diffusivity/conductivity among the tested rocks from Hong Kong. Sandstone, basalt, and feldsparphyric rhyolite showed moderate levels of thermal diffusivity/conductivity. Siltstone, metasandstone, granodiorites, and tuff-Tai Mo Shan Formation displayed the lowest thermal diffusivity/conductivity.

- Hong Kong basalt is considered an ideal candidate for high-temperature thermal energy storage material, with 850 °C identified as the appropriate maximum working temperature. Other igneous rocks found in Hong Kong can be utilized for TES engineering applications within the mid-to-low temperature range (100 – 500 °C). However, sedimentary and metamorphic rocks in Hong Kong do not appear to be suitable.

The testing results presented herein contribute to our comprehension of the alterations in the thermophysical properties of Hong Kong rocks under heating conditions. Additionally, they offer valuable insights into parameter configurations for numerical simulations aimed at the future design of storage systems and the prediction of their operational efficacy.

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