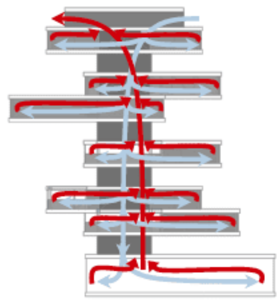
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	蟻丘促進氣體交換 (Mound Facilitates Gas Exchange)
生物系統 LIVING SYSTEM	築蟻丘白蟻 Isoptera (Mound-building termites)
功能類別 FUNCTIONS	#獲取、吸收、或過濾能量 #分配氣體 #Capture, Absorb, or Filter Energy #Distribute Gases
作用機制標題	地面上大白蟻丘的結構利用太陽熱力推動內部氣流，促進地面下巢穴的氣體交換 (The structure of above-ground macrotermite mounds facilitates gas exchange in the below-ground nest using internal air currents driven by solar heat.)
生物系統/作用機制示意圖	 

作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)

築蟻丘大白蟻 (Mound-building macrotermites) 會利用土壤、唾液 (saliva) 和糞便等建造出垂直的蟻丘 (mound)，非洲的一些蟻丘還可以高達幾公尺。這些蟻丘乍看與煙囱相似，但不同物種會以不同的方式使牠們的蟻丘變得通風 (ventilate)。有些物種會建造出帶有煙囱或通氣孔 (vent hole) 的「開放式」蟻丘，而另一些會建造出沒有大型開口但有穿孔外壁 (porous wall) 的「封閉式」蟻丘。在這兩種蟻丘中，工蟻 (worker) 都可以挖出各種大小、排列複雜的隧道。白蟻成群生活在地下的巢穴中，可容納多達一百萬個個體。

最近發表的研究指出，白蟻丘的功能與哺乳類肺部的作用類似，並充當附屬器官 (accessory organ)，負責巢穴中的氣體交換。白蟻丘的作用以前被認為是在極端的外部溫度波動之下，能將巢穴內部溫度持續地維持在一定的範圍內，但是對於會建造封閉式蟻丘的築蟻丘白蟻如*Macrotermes michaelseni*的研究加深了我們對蟻丘功能的瞭解。白天時，巢穴內部的溫度變化比外部溫度變化小，但在一年間，巢穴溫度通常會緊隨周圍土壤的溫度而變化。土壤的熱容量 (heat capacity) 很大，意味著它在任何溫度變化下都可以吸收或失去大量的熱能。從某種意義上說，白蟻巢周圍的土壤充當緩衝層 (buffer)，抵抗外界溫度的日夜變化。

研究人員正積極地研究白蟻丘，以精確地瞭解蟻丘結構如何促進地面下族群的氣體交換。主要機制是透過陽光熱力來帶動內部空氣流動，隨著外部溫度在一天中的變化，以及陽光照射在蟻丘的不同表面，蟻丘外圍和中心之間會形成溫度梯度，在蟻丘內部產生上升

和下降氣流，這些氣流隨著溫度梯度在一天中的變動而改變。蟻丘外部的不穩定氣流產生的風能也可對通風起次要作用，內部氣流可能會促進蟻丘與巢穴中的空氣混合，最終促進巢穴中的氣體交換。

Mound-building macrotermites construct vertical mounds out of soil, saliva, and dung, with some mounds in Africa measuring up to several meters high. The mounds generally resemble chimneys, but different species ventilate their mounds in different ways. Some species may create 'open' mounds with chimneys or vent holes, while others build 'closed' mounds that lack large openings but have porous walls. Inside both of these mounds, worker termites can dig a complex array of tunnels of various sizes. The termites themselves live in nests below ground in colonies that can contain up to a million individuals.

The most recent published research on termite mounds suggests that they function much like mammalian lungs and act as accessory organs for gas exchange in the underground nests. It was previously thought that termite mounds functioned to continuously maintain the nest's internal temperature within a narrow range in the face of extreme outside temperature fluctuations, but research on mound-building termites like *Macrotermes michaelseni*, which construct closed mounds, is expanding our understanding of how these mounds function. During the day, changes in internal nest temperature are less extreme than changes in outside temperature, but over the course of a year, nest temperature does vary and closely follows the temperature of the surrounding soil. The soil has a large thermal capacity, meaning it can absorb or lose large amounts of heat energy before experiencing any changes in temperature. In a way, the soil around the termite nest acts as a "buffer" against daily changes in outside temperature.

Researchers are actively studying mounds to understand precisely how mound structure facilitates gas exchange in the underground colony. It appears that the main mechanism is through internal air currents driven by solar heat. As outside temperatures change throughout the day and the sun strikes different surfaces on the mound, temperature gradients develop between the mound periphery and center. These temperature gradients create currents of rising and falling air inside the mound. The direction of these currents varies as temperature gradients change throughout the day. Wind energy from unsteady airflows outside the mound may also play a secondary role in ventilation. The internal airflows likely promote mixing between air in the mound and air in the nest, ultimately facilitating gas exchange in the nest.

文獻引用 (REFERENCES)

「最近在一種亞洲南部白蟻 *Odontotermes obesus*蟻丘中的實驗證據提出，輻射加熱 (radiant heating) 在一天中的振盪頻率 (oscillation) 伴隨著晝夜日射 (diurnal insolation) 的方式，驅動了蟻丘內部的空氣對流 (convective flow)。目前該機制的普遍性尚不清楚。為了探討此問題，我們研究了生長環境截然不同的另一非洲白蟻物種 *Macrotermes michaelseni*之蟻丘。透過直接測量蟻丘內的風速 (air velocity) 和溫度，我們觀察到所涉及的整體機制和模式都與亞洲南部的白蟻物種相似。」Ocko SA et al 2020: 220

「大多數建築設計中，牆壁會建造作為隔離空間：內部空間與外部世界，以及內部的各個空間等等。但如果空間要被佔用或使用，則不能被完全隔離。解決這個悖論 (paradox) 的方法是在建築設計中包含基礎設施 (infrastructure) 如窗戶、風扇、管道、空調、暖氣等，所有這些設施在本質上都是為了去除牆壁一開始的作用。簡單來說，這個悖論迫使建築設計朝著所謂的「建築物就像機器」典範來設計。生命系統同時也是空間創造者，它以另一個方式解決悖論：透過建立非障礙物而是適應性介面 (adaptive interface) 的牆壁，物質和能量流動不是被牆壁阻擋，而是由牆壁本身決定是否阻擋或穿透。」Turner JS et al. 2021: 13CON

"Recent experimental evidence in the mounds of a single species, the south Asian termite *Odontotermes obesus*, suggests that the daily oscillations of radiant heating associated with diurnal insolation patterns drive convective flow within them. How general this mechanism is remains unknown. To probe this, we consider the mounds of the African termite *Macrotermes michaelseni*, which thrives in a very different environment. By directly measuring air velocities and temperatures within the mound, we see that the overall mechanisms and patterns involved are similar to that in the south Asian species." Ocko SA et al 2020: 220

"In most building designs, walls are erected as barriers to isolate spaces: internal spaces from the outside world, internal spaces from one another and so forth. Yet spaces, if they are to be occupied and used, cannot be isolated. Resolving this paradox is what forces building designs to include infrastructure—windows, fans, ducts, air conditioning, heating etc—all essentially to undo what the erection of the walls did in the first place. In short, the paradox forces building design toward what we call the"building-as-machine" paradigm. Living systems, which also are avid space-creators, resolve the paradox in a different way: by erecting walls that are not barriers but adaptive interfaces, where fluxes of matter and energy across the wall are not blocked but are managed by the wall itself." Turner JS et al. 2021: 13CON

參考文獻清單與連結 (REFERENCE LIST)
Ocko, S. A., H. King, D. Andreen, P. Bardunias, J. S. Turner, R. Soar, and L. Mahadevan. (2017). Solar-powered ventilation of African termite mounds. *Journal of Experimental Biology* 220: 3260-3269. (https://jeb.biologists.org/content/220/18/3260)
延伸閱讀**: Harvard** 或 **APA** 格式（取自 **AskNature** 原文；若為翻譯者補充，請註明）
生物系統延伸資訊連結 (LEARN MORE ABOUT THE LIVING SYSTEM/S)
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撰寫/翻譯/編修者與日期
羅敬堯翻譯 (2021/04/05)；譚國鋈編修 (2021/07/28)；林有駿編修 (2021/12/27)；陳柏宇編修 (2022/01/02)
AskNature原文連結
https://asknature.org/strategy/mound-facilitates-gas-exchange/