生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	堅硬而又可伸展的黏合劑 (Adhesive is both strong and flexible)
生物系統 LIVING SYSTEM	牡蠣 *Crassostrea virginica* (Eastern oyster)
功能類別 FUNCTIONS	#永久性附著 #控制沖蝕及沉積 #透過自我組織維持群落協調 #氣體/水分/廢物解毒/淨化 #應付亂流 #Attach permanently #Control erosion and sediment #Coordinate by self-organization #Detoxification/purification of air/water/waste #Manage turbulence
作用機制標題	牡蠣使用在黏性蛋白質網絡中的礦物質建構強力但具伸展性的礁石 (Oysters build strong but flexible reefs using minerals in a sticky protein web)
生物系統/作用機制示意圖	
作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)	

牡蠣對某些人來說是佳餚，也是部分人的主要食物，但牠們同時也是海岸生態系統中重要的一部分。牡蠣會互相緊抓在一起，堆疊得像是從海底長出的石筍 (stalagmites)。經過一段時間之後，牡蠣的群落會形成龐大的礁石，就像是海中城市一樣。牠們為許多海洋物種提供了棲息地、過濾海水並改善水質，以及減緩海浪及船隻交通造成的波浪，保護海岸線免受沖蝕。

Jonathan Wilker 博士是普渡大學 (Purdue University) 的化學教授，研究牡蠣與其他海洋生物如何產生關聯。雖然很多海洋生物會產生蛋白質黏膠，但 Wilker 指出牡蠣的黏

合劑是獨特的，因為除了少量的蛋白質主要有機成分之外，它還含有大量的無機碳酸鈣 (calcium carbonate)。

碳酸鈣，又稱為石灰 (limestone)，並沒有黏性。所以到底牡蠣的黏合劑是如何作用呢？
就如同摩天大樓需要同時兼具堅固及伸展性，以容許在風中輕微地搖晃（不至於倒塌），牡蠣組合了碳酸鈣以及較為柔軟黏稠的蛋白質，使其能夠抵擋強烈的潮汐力量，並將牠們的群落固定在一起。

在 2010 年，Wilker 的研究發現了蛋白質分子進行交叉鏈接 (cross-link) 的證據，顯示這些物質形成了一種篩網或是蜘蛛網的形狀，使所有成分互相接合，並賦予黏合劑的黏性。試想像一面磚牆，灰泥（作用如同有機物）黏合磚塊到另一磚塊或者其它表面上，而磚塊（作用像碳酸鈣）則增加強度與剛性。

真實的磚牆都有其規律的樣式，牡蠣黏合劑的結構卻可以完全不必遵循這個原則。Wilker 正在進行的研究持續地揭露錯綜複雜的事物。舉例來說，不似牡蠣自身的外殼單純僅含一種碳酸鈣，牡蠣的黏合劑使用了兩種在化學上相同，但由不同形狀及方向的晶體所組成的碳酸鈣。另有其他研究結果顯示，這種黏膠可能混入其他水中環境的物質，並可能涉及與細菌的共生作用，會將醣類加入到有機質中。

Wilker 的研究工作其中一個目標，簡單來說就是去了解自然如何製造出材料。他說：「了解事物的本身是非常令人興奮的。」。他也指出這項研究有很大的醫療應用潛力，包括了骨骼修復及牙齒黏合劑，這些都牽涉在濕潤環境中黏合無機物質。另外，這項研究也有助於發展更環保的水泥製品，可以用於對海洋友善的海岸工程建設，並幫助恢復全球在過去一個世紀中，因人類活動而消失了 85%左右的牡蠣礁。

Oysters are a delicacy to some and a staple food to others, but they are also vital to coastal ecosystems. Oysters grab on to one another, stacking themselves like stalagmites that grow from the ocean floor. Over time, oyster clumps form extensive reefs that resemble underwater cities. They provide habitat to many aquatic species, filter water and improve its quality, and dampen waves caused by storms and ship traffic, protecting coastlines from erosion.

Dr. Jonathan Wilker, chemistry professor at Purdue University, studies how oysters and other marine animals create their underwater bonds. Although many marine animals produce a protein “glue,” Wilker says that oyster cement is unique because—in addition to a small amount of mostly-protein organic matter—it contains a high quantity of inorganic calcium carbonate.

Calcium carbonate, otherwise known as limestone, is not at all adhesive. So how does oyster cement work? Similar to how skyscrapers must be both rigid and flexible to allow slight swaying in the wind (without toppling), oysters combine hard calcium carbonate with softer, stickier proteins, enabling them to withstand strong tidal forces while holding their colonies together.

In 2010, Wilker's research found evidence that the protein molecules "cross-link," meaning they form a kind of mesh or spider web that binds all the ingredients together and gives the cement its stickiness. Imagine a brick wall, where the mortar (acting like the organics) glues the bricks to one another as well as to other surfaces, while the bricks (behaving like calcium carbonate) add strength and rigidity.

While an actual brick wall follows a regular pattern, the structure of oyster cement is far from uniform. And Wilker's ongoing research continues to reveal complexities. For example, unlike oyster shells themselves, oyster cement uses two kinds of calcium carbonate, chemically equivalent but made from crystals having different shapes and orientations. Other results indicate that the adhesive may incorporate material from its aquatic environment and may even involve symbiosis with bacteria that add sugars to the organic portion.

One of Wilker's goals of this work is to simply understand how nature makes materials. "That, in itself, is pretty exciting," he said. But he points out that this research has a range of potential medical applications, including for bone repair and dental cements, which involve adhering inorganic materials in wet environments. In addition, this work is leading to greener concrete products that can be used to build marine-friendly human structures along shorelines—and help recover some of the 85% of oyster reefs that have disappeared globally over the past century due to human activity.

文獻引用 (REFERENCES)

「在此展示的實驗證實了牡蠣產生出生物礦化 (biomineralized) 黏合物質，以聚集成龐大的群落。這種黏合劑是一種有機-無機混合物，並與旁邊的貝殼有所不同，它們展現出不同的 $CaCO_3$ 晶體型態，作為一種交叉鏈接的有機基質，以及提高了蛋白質含量。」

「這種黏合劑被證實在化學組成及微米尺度的亞微米 (sub-micron) 結構上都是不一致的。這種非一致性顯示這種黏合劑可能在開放環境中形成，允許這種貝類使用周遭的元素及物質。這種獨特的黏合劑提供了特殊的材料特性，以及透過難以置信地堅硬的內容物來增加強度，而其主要的黏合劑則是柔軟的，因此也提供了伸展性。」

"Experiments presented here show that oysters generate a biomineralized adhesive material for aggregating into large communities. This cement is an organic-inorganic hybrid and differs from surrounding shells by displaying an alternate CaCO3 crystal form, a cross-linked organic matrix, and an elevated protein content."

"The adhesive was shown to be non-uniform in both chemical composition and structure from sub-micron up through millimeter length scales. This non-uniformity suggests the adhesive is formed in an open environment, enabling the shellfish to utilize elements and materials from the surroundings. This unique adhesive provides distinctive materials properties with inclusions being incredibly hard, for enhancing strength, while the majority of the adhesive is soft, thereby providing flexibility."

參考文獻清單與連結 (REFERENCE LIST)

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延伸閱讀

生物系統延伸資訊連結 (LEARN MORE ABOUT THE LIVING SYSTEM/S)

https://en.wikipedia.org/wiki/crassostrea_virginica
https://www.onezoom.org/life/@crassostrea_virginica
https://eol.org/pages/449554

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https://asknature.org/strategy/adhesive-is-both-strong-and-flexible/