生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	蠕蟲耐受華氏140度的溫度差 (Worm Tolerates Temperature Gradient of 140 Deg F)
生物系統 LIVING SYSTEM	龐貝蠕蟲 *Alvinella pompejana* (Pompeii worms)
功能類別 FUNCTIONS	#保護免受溫度危害 # Protect From Temperature
作用機制標題	**龐貝蠕蟲利用多種策略忍受地球上升降最劇烈的溫度梯度** (Pompeii worms tolerate the steepest temperature gradient on the planet using multiple strategies)
生物系統/作用機制示意圖	

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

「我的一些同事已經提名龐貝蠕蟲 (*Alvinella pompejana*)（右）為地球上最耐高溫的動物。所有龐貝蠕蟲科 (alvinellids) 都生活在海底黑煙囪 (black smokers) 側面的管口裡，位於噴口 (vent) 最沸騰的中心。德拉瓦大學 (University of Delaware) 海洋生物學家Craig Cary收集到的數據顯示，龐貝蠕蟲科生活在華氏149度的水中，並能在經過超過175度的高溫波動中生存下來。龐貝蠕蟲科平均直徑為半英寸，長約三英寸，能忍受地球上升降最劇烈的溫度梯度。有人曾採集到龐貝蠕蟲的標本，兩端的水相差140華氏度。來自黑煙囪的過熱 (overheated) 液體與周圍的冷海水不能均勻地混合，所以它們之間的過渡很不連貫。Cary說：『教科書上的生物學告訴我們，動物可以是嗜冷型 [愛冷的] 或嗜熱型 [愛熱的]，但不能兩種特性兼備。我想龐貝蠕蟲科只是沒有讀教科書。』。我們還不知道龐貝蠕蟲是如何在這些極端條件下生存的。答案可能在於牠們的行為或一些特殊的細胞生物化學 (cellular biochemistry)，或兩者都有。」(Lutz 2000)

「龐貝蠕蟲能夠承受高達105℃的溫度 (Chevaldonne et al. 1992)，並被稱為是最具廣溫性 (eurythermal) 的後生動物 (metazoan) (Haddad et al. 1995)。Brisa et al. (2005) 進行的實驗表明龐貝蠕蟲影響了煙囪壁和周圍海水之間界面的礦化 (mineralization) 過程。該研究還表明，龐貝蠕蟲透過建構溫度及化學梯度對其環境進行基本的控制，透過建造保護性管子來創造精細的微環境 (micro-environment)。透過管子供水能防止曝露在極端的溫度波動和高濃度的硫化物 (sulphide) 中。避開熱液噴發等的不穩定巨變，龐貝蠕蟲的管子創造了更均勻 (homogeneous) 的化學和熱微生態系統 (mocroniche)，並可能在微生物多樣性方面發揮作用。」

「膠原蛋白是動物界 (animal kingdom) 中最普遍的蛋白質之一，可以在海綿以及脊椎動物 (vertebrate) 中發現 (Scandurra et al. 2000) 。膠原蛋白 (collagen) 是具有三螺旋結構

(triple-helical domains) 的細胞外蛋白 (extracellular protein) (vander-Rest & Garrone 1991)。在膠原蛋白中，最相似的亞家族 (subfamily) 是纖維膠原蛋白 (fibrillar collagen) (Wharton & Brown 1991)。纖維膠原蛋白擁有一個長型中央三螺旋結構域，由330至340個GNN三聯體 (tripet) 組成，兩側有一個氨基前肽 (N- propeptide, N-pro) 和一個羧基前肽 (carboxyl-propeptide , C-pro)。膠原蛋白不僅在細胞之間凝聚，在細胞分化和遷移中也扮演重要角色 (Wharton & Brown 1991; vander-Rest & Garrone 1991)。沿海多毛類蠕蟲 (polychaete worm)（例如沙蟲*Arenicola marina*）的間質膠原蛋白 (interstitial collagen) 在28 °C時變性，而龐貝蠕蟲的膠原蛋白在45 °C時仍然穩定，是已知最耐熱的纖維狀膠原蛋白(Gaill et al. 1995)。牠的膠原蛋白在高溫(Gaill et al. 1995) 高壓下 (Auerbach et al. 1995) 的穩定性，以及其相關的酵素過程，在缺氧 (anoxic) 條件下有最佳活性，可適應深海熱泉 (hydrothermal) 的環境。」(Kaule et al. 1998)

「這種熱活動方式 (thermal behavior) 的分子基礎 (molecular basis) 包括增加脯氨酸 (proline) 含量和穩定三聯體的數量，這與龐貝蠕蟲的間質膠原蛋白傑出之熱穩定性 (thermostability) 相關。脯氨酸殘基 (residue) 在膠原蛋白三螺旋間的內聚力極為重要 (vander-Rest & Bruckner 1993; Prockop & Kivirikko 1995)。生物化學分析至今無法解釋龐貝蠕蟲膠原蛋白的熱穩定性 (Gaill et al. 1995)。Sicot et al. (2000) 採用分子遺傳方法，複製並定序了一段大的cDNA分子，為龐貝蠕蟲纖維狀膠原蛋白的編碼，包括一半的螺旋結構域和整個羧基-前肽結構域。為了進行比較，該團隊還從大管蟲(*Riftia*) 複製了部分同源cDNA (homologous cDNA) (Pohlschroder et al. 1997)。比較這兩個物種相應的螺旋結構，以及沙蟲的序列 (Sicotet al. 1997)，顯示增加脯氨酸含量和穩定三聯體的數量與龐貝蠕蟲的間質膠原蛋白出色的熱穩定性有關。親緣演化分析 (phylogenetic analysis) 顯示，同一膠原蛋白分子的三螺旋和羧基前肽部分以不同的速度演化，有利於分子層面上的適應。(Islam & Schulze-Makuch 2007: 207)

“Some of my colleagues have nominated the worm Alvinella pompejana (right) as the most thermally tolerant animal on Earth. Whole galleries of alvinellids live in tubes on the sides of black smokers, at the very seething heart of the vent. University of Delaware marine biologist Craig Cary has gathered data that show alvinellids living in water that’s 149 °F and surviving frequent temperature spikes well above 175 °F. Alvinellids–on average a half inch in diameter and about three inches long–also tolerate the steepest temperature gradient on the planet. Specimens have been found in water 140 °F hotter at one end of the animal than at the other. Superheated fluids from black smokers do not mix well with ambient cold seawater, so transitions between them are abrupt. ‘Textbook biology tells us that animals can be psychrophilic [cold loving] or thermophilic [heat loving] but not both,’ says Cary. ‘I guess the alvinellids just didn’t read the textbook.’ We don’t yet know how *Alvinella* worms survive these extremes. The answer may lie in their behavior or in some specialized cellular biochemistry, or both.” (Lutz 2000)

“The Pompeii worm is capable of withstanding temperatures as high as 105 °C (Chevaldonne et al. 1992), and is known as being the most eurythermal metazoan (Haddad et al. 1995). Experiments carried out by Brisa et al. (2005) demonstrated that *A. pompejana* influences mineralization processes at the interface between the smoker wall and the ambient oceanic water. The study also indicated that *A. pompejana* exerts a primary control on its environment by structuring the thermal and chemical gradients, creating a mosaic of micro-environments by the construction of protective tubes. The supply of water through the tube prevents exposure to the extreme temperature spikes and high sulphide concentrations. Circumventing the large erratic changes generally associated with hydrothermal venting, *A. pompejana* tubes create more homogeneous chemical and thermal microniches and likely play a role in microbial diversity.”

“Collagens are among the most ubiquitous proteins found in the animal kingdom and can be found in sponges as well as in vertebrates (Scandurra et al. 2000). Collagens are extracellular proteins with triple-helical domains (vander-Rest & Garrone 1991). Among collagens, the most homogeneous subfamily is that of fibrillar collagens (Wharton & Brown 1991). Fibrillar collagens possess a long central triplehelical domain of 330 to 340 GNN triplets, flanked by an amino-propeptide (N-pro) and a carboxyl-propeptide (C-pro). Collagens are of great importance, not only in performing cohesion between cells, but also in cell differentiation and migration (Wharton & Brown 1991; vander-Rest & Garrone 1991). Whereas the interstitial collagen of coastal polychaete worms (e.g. *Arenicola marina*) is denatured at 28 °C, the collagen of *A. pompejana* remains stable at 45 °C and is thus the most thermostable fibrillar collagen known (Gaill et al. 1995). Its collagen is adapted to the hydrothermal vent environment by its stability at higher temperatures (Gaill et al. 1995) and high pressures (Auerbach et al. 1995), and by its associated enzymatic processes, which appear to be optimized under anoxic conditions." (Kaule et al. 1998)

"The molecular basis of this thermal behaviour includes the increase in proline content and in the number of stabilizing triplets, which correlate with the outstanding thermostability of the interstitial collagen of *A. pompejana*. Proline residues are of primary importance in performing cohesion between the chains of the triple helix of collagens (vander-Rest & Bruckner 1993; Prockop & Kivirikko 1995). Biochemical analysis has so far been unable to explain *Alvinella*'s collagen thermostability (Gaill et al. 1995). A molecular genetic approach has been used by Sicot et al. (2000), who have cloned and sequenced a large cDNA molecule coding the fibrillar collagen of *Alvinella*, including one-half of the helical domain and the entire C-propeptide domain. For comparison, the group also cloned part of the homologous cDNA from *Riftia* (Pohlschroder et al. 1997). Comparison of the corresponding helical domains of these two species, together with that of the sequenced domain of the coastal lugworm *Arenicola marina* (Sicot et al. 1997), showed that the increase in proline content and in the number of stabilizing triplets correlates with the outstanding thermostability of the interstitial collagen of *A. pompejana*. Phylogenetic analysis showed that the triple helical and the C-propeptide parts of the same collagen molecule evolve at different rates, in favour of an adaptive mechanism at the molecular level." (Islam & Schulze-Makuch 2007: 207)

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