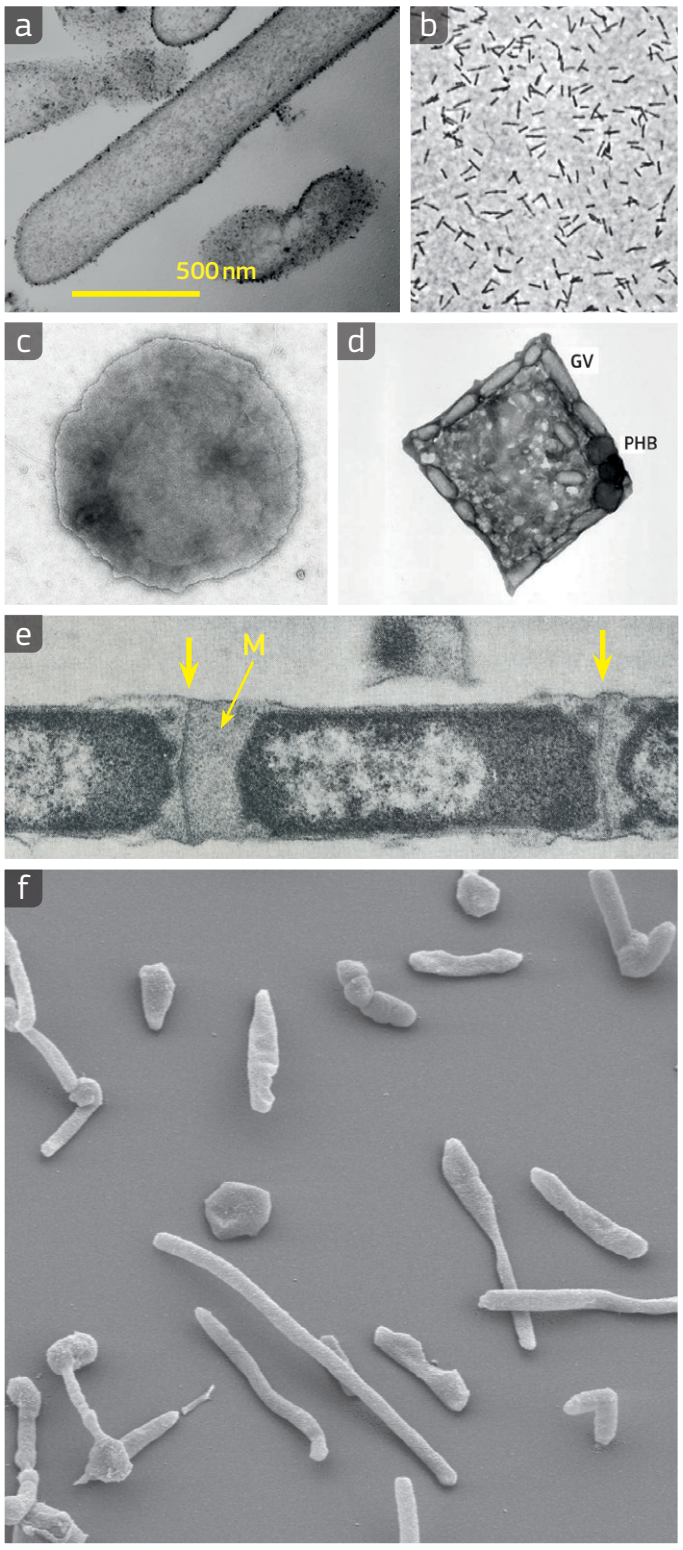
Prokaryota – Archaea

Morphology

Archaea are unicellular microscopic organisms with a striking variety of cell shapes (pleomorphism) and unique geometric forms [25]. Many are rod-like (referred to as bacilli – e.g. *Methanocella* and *Methanobrevibacter*) or spherical (referred to as cocci – e.g. *Methanococcus*) while the heat-loving (thermophiles) *Sulfolobus* are highly irregular cocci. By contrast, *Methanosaeta* and *Methanospirillum* have both a long rod shape (filamentous) with sheaths that surround adjoining cells. Additionally, some archaea (e.g. *Methanosarcina*) form clusters, while the cells of *Haloterrigena* form many irregular shapes. Some species belonging to Halobacteriales can be square-shaped, triangles or flat discs.



Diversity of cellular shapes in the archaea: (**a**) Transmission electron microscopy (TEM) image and (**b**) phase contrast micrograph of rod-shaped *Methanocella conradii* cells; (**c**) TEM image of a coccoid *Methanococcus*; (**d**) Scanning electron microscopy (SEM) image of a square Halobacteriales cell with visible gas vesicles (GV); (**e**) TEM image of a *Methanosaeta* sheaf of cells, showing the spacer plug (arrowheads) and amorphous granular matrix (M); (**f**) SEM image of pleiomorphic *Haloterrigena turkmenica* cells. (ZL, DBN, DGB, TJB, ELS)

Diversity, abundance and biomass

Over 300 archaeal species have been described, primarily found in extreme environments. However, many more species have been detected in the environment but it is not possible to isolate and describe them. Soils contain between 10^5 and 10^{10} microbial cells in each gramme (0.04 ounces), and all contain archaea. Generally, up to 10 % of microbial cells in temperate soils may be archaea (mesophilic species), while in conditions of high temperature, high salinity or at high or low pH, archaea (extremophilic species) can be the dominant members of the microbial community.

Taxonomy

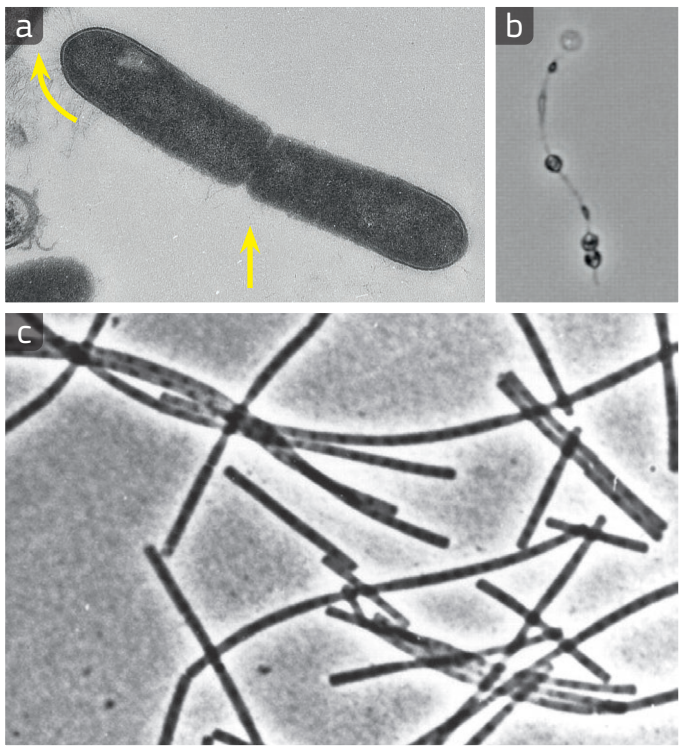
Archaea, the third domain of life (see page 31), were originally split into two phyla, the Euryarchaeota and the Crenarchaeota. The Crenarchaeota have now been divided to make a new phylum, the Thaumarchaeota. There may be other phyla, such as the Korarchaeota, Nanoarchaeota and Aigarchaeota, but whether these represent true distinct phyla is disputed. The Euryarchaeota are physiologically the most diverse, with a number of methane-producing orders (methanogens); the aerobic, salt-loving (halophilic) Halobacteriales; the thermophilic, Thermoplasmalates, sometimes lacking a cell wall; and several 'orders' with members that are not yet described. The Crenarchaeota are almost all extremophiles, living at high temperatures or extremes of pH (see boxes below) and are primarily involved in sulphur or iron metabolism. The Thaumarchaeota contain most of the isolated mesophilic archaea, which are associated with aerobic ammonia oxidation (nitrification). All three major phyla also contain many undescribed groups and we know little about their ecology and physiology.

Microorganisms and the environment

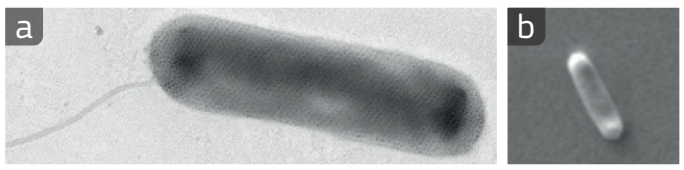
- Some microorganisms, including the archaea, are able to modify their shape or size in response to environmental conditions – this is also known as pleomorphism.
- Organisms that exist only in moderate temperatures, typically between 20°C and 45°C, are referred to as mesophiles.
- By contrast, extremophiles are organisms that thrive in extreme environmental conditions. It is possible to have different classes of extremophiles, depending on the evironmental factors:
  - thermophile: an organism that loves high temperature;
  - psychrophile: an organism that loves low temperature;
  - alkaliphile: an organism that loves high pH values;
  - acidophile: an organism that loves low pH values;
  - halophile: an organism that loves high salt concentration.

The versatile archaea

- The discovery of archaea altered our understanding of evolution, but recent research suggests that eukaryotes evolved from archaea. So humans may actually be derived from archaea.
- Archaea live in the widest range of environmental conditions of any organisms, from pH 0 to pH 12, 0°C to 120°C, and up to 35 % salinity.
- Hyperthermophilic archaea survive at temperatures greater than 90°C by having a thin membrane, made up of double-headed lipids, that insulates the cell interior from the heat. In acid or salty environments, this sort of membrane acts as a barrier to water molecules and other ions.
- The halophilic archaeon, now called *Haloquadratum walsbyi*, was for a long time known as 'Walsby's square bacterium' as it is box shaped and forms large fragile flat sheets in the environment.
- Archaea do not have a nucleus.



Euryarchaeota: (**a**) TEM image of a *Methanobrevibacter* from the gut of a soil insect; (**b**) Light micrograph of a Thermoplasmalates – its cells joined like beads on a string; (**c**) SEM image of *Methanosaeta* filaments. (JRL, TI, RG)



Thaumarchaeota: (**a**) SEM image of '*ca.* Nitrosotenuis uzonensis', a thermophilic ammonia oxidiser that is able to convert ammonia into nitrogen; (**b**) SEM image of *Nitrosotalea devanaterra*, an acidophilic that is also able to oxidise ammonia. (EVB, LEL)

Microhabitat

Euryarchaeota, in particular methanogens, dominate waterlogged soils. Six of the seven methanogen orders can be found in different soil types, either free-living or associated with other organisms, such as ciliates and termites. Methanogens can also be found in dry and aerated soils. Members of the Halobacteriales order are often found in high salinity soils, and many use light as an energy source. Archaea in soils under termperate climates are dominated by the Thaumarchaeota, a group that was previously linked to the Crenarchaeota. Many Thaumarchaeota are able to convert ammonia to nitrite (amonia-oxidisers). In low pH soils, and under low ammonia and low oxygen conditions, these archaea are more important than their bacterial counterparts. There are also non-ammonia oxidising Thaumarchaea, but it is not possible to isolate these in the laboratory (see pages 64-65); therefore, they remain uncharacterised. The extremophilic Crenarchaeota are primarily found in harsh soils, such as hot volcanic soils, rich in sulphur and iron compounds. A unique group was found to be the dominant archaea in high acidic, deeply weathered, red soils (Ferralsols – see pages 26-27) in China.

An extremely hot, sulphur-rich environment (Campi Flegrei, Italy). Thermophilic Archaea of the phylum Crenarchaeota can be found in the soils around volcanic vents (fumaroles). (YIF)