# Salt Making in Antiquity and in the Middle Ages – A Microbiologist's Perspective

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For a microbiologist, coastal saltern ponds are among the most beautiful study objects, as the dense and colorful communities of microorganisms that develop in the brines and on the bottom of the evaporation ponds are often so prominent that their presence is obvious to all. The sediments of evaporation ponds of intermediate salinities are generally covered by dense mats of dark-green or orange colored cyanobacteria, brown diatoms, and purple photosynthetic bacteria. The salt-saturated brines of the crystallizer ponds where halite precipitates have a characteristic red-purple to orange color, caused by different types of pigmented microorganisms. These include the unicellular green alga *Dunaliella salina* that is rich in the orange pigment β-carotene, a variety of red-purple halophilic archaea, including the square-rectangular flat *Haloquadratum walsbyi*, that contain bacterioruberin carotenoids and retinal proteins such as bacteriorhodopsin, and red bacteria of the genus *Salinibacter*. Red is the "magic color for solar salt production" [1]. The presence of $10^7$-$10^8$ such prokaryotes per milliliter of brine, in addition to several thousands of *Dunaliella* cells, imparts the red color of the brine seen in most salt producing facilities worldwide [2]. The pigmented microbial communities absorb sunlight, thereby increasing the water temperature, enhancing water evaporation, and increasing the rate of halite crystallization.

It is surprising that the red color of saltern brines was first mentioned in written sources only relatively recently [3]. A clear record of red brines associated with salt production in the Western world is to my knowledge first found in the *Encyclopédie* of Diderot: "*On connoît que le sel se forme quand l'eau rougit; c'est en cet état qu'étant réchauffé par le soleil & par le vent, il se crême de l'épaisseur de verre* ..." [4]. In China, such red brines were documented earlier: Li Shizhen, who in the 16$^{th}$ century compiled a treatise of traditional Chinese medicine and pharmacology, wrote: "... a pool surrounded by an embankment. They put clear seawater in it. Many days later, the water will be red" [5,6].

Therefore, it is interesting to explore to what extent coastal salterns in Roman times may also have displayed these characteristic red colors. In book XXXI of his *Historia Naturalis*, Plinius [7] mentioned many places where salt was produced in evaporation ponds, which was the most common way of obtaining salt at the time: *facticii varia genera, volgaris plurimusque in salinis mari adfuso* (Of artificial salt there are various kinds. The usual one, and the most plentiful, is made in salt pools by running into them sea water ...). Plinius described two techniques of gathering salt, the first involving

complete evaporation of the water leaving a salt crust (*omnis e stagnis sal minutus atque non glaeba est*), the second being directly harvesting of the salt from the brine, as also described by Manilius [8] (see below). Plinius mentioned salt of different shades of red (*rubet Memphi, rufus est circa Oxum, Centuripis purpureus* ...; blushing red at Memphis, tawny red near the Oxus, purple at Centuripae), but these do not refer to places with coastal salterns.

From the Roman antiquity, we have descriptions how salt was produced by evaporation of seawater. In his *Astronomica* (~10–20 CE), Marcus Manilius wrote:

> *... cum solidum certo distendunt margine campum appelluntque suo deductum ex aequore fluctum claudendoque negant abitum: sic suscipit undas area et expoto per solem umore nitescit. congeritur siccum pelagus mensisque profundi canities detonsa maris, spumaeque rigentis ingentis faciunt tumulos, ...*
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> ... they prepare a wide expanse of hardened ground and surround it with firm walls, next conduct therein waters channeled from the nearby sea and then deny them exit by closing sluice-gates: so the floor holds in the waves and begins to glisten as the water is drained off by the sun. When the sea's dry element has collected, Ocean's white locks are shorn for use at table, and huge mounds are made of the solid foam; ... [8].

In his poem entitled *De Reditu Suo sive Iter Gallicum* (About his Return, or, a Journey to Gaul), Rutilius Claudius Namatianus described a visit to the salterns near Volterra in the year 416:

> *Subiectas villae vacat aspectare salinas; namque hoc censetur nomine salsa palus, qua mare terrenis declive canalibus intrat multifidosque lacus parvula fossa rigat ... tum cataractarum claustris excluditur aequor, ut fixos latices torrida duret humus; concipiunt acrem nativa coagula Phoebum et gravis aestivo crusta calore coit, ...*
>
> We have time to visit the salterns below the country house; for by this term one designates the salt marsh where seawater enters through sloping earthen channels and where a small ditch conducts water to the basin, divided into many parts ... then the water level is cut off by the barriers of sluices, so that the dry soil will become hard due to the fixed liquids. The created solid crust received the stinging sun, and a heavy crust is united by the heat of the summer, ... [9].

Neither Manilius nor Namatianus mentioned a red color in the water in the harvesting ponds. This does not imply that the brines were not red, but one may argue that, if indeed dense communities of pigmented microorganisms populated the salterns at the time, these authors would have noticed and mentioned colors.

There is a reasonable explanation why the Roman authors did not make any statements about red saltern brines and why these colors were only noticed much later (for example, *De Re Metallica*, the 16$^{th}$ century textbook by Georgius Agricola did

not mention them): in earlier times the salt production ponds may not have been red [3]. This can be explained by the different way such salterns were operated now and then. In modern salt production facilities, the crystallizer ponds are filled and the water is left to evaporate for many weeks until a sufficiently thick layer of salt has accumulated on the bottom. The Chinese practiced the same method ("They put clear seawater in it. Many days later, the water will be red") [5]. In the method traditionally practiced around the Mediterranean, salt was harvested several times per week during the summer [10], so that the residence time of the brine was not long enough to allow the development of microbial communities dense enough to impart a red color to the brines. At several sites, this traditional technology of salt production is still practiced today. In the salterns near Sečovlje on the border between Slovenia and Croatia and near Ston, Croatia, both operated as they were in the Middle Ages, the crystallizer brines are not red. They contain less than $10^7$ pigmented microorganisms per milliliter, so an order of magnitude less than the red brines that characterize most modern coastal salt production facilities [3].

In the salterns near Sečovlje, another ancient technology is practiced today: the cultivation of microbial mats, traditionally called 'petola', on the bottom of the salt production ponds. The main microbial component of this petola mat is a filamentous cyanobacterium, earlier named *Microcoleus* and today known as *Coleofasciculus chthonoplastes* [11, 12]. This microbial mat effectively seals the bottom of the ponds and prevents contamination of the salt with mud from the pond bottom. In the spring, petola is 'fertilized', regenerated with fresh black silt. At Sečovlje, petola was introduced from the Croatian island Pag in the end of the 14$^{th}$ century. Whether such microbial mats were cultivated in coastal salterns in Roman times is unknown.

Plinius [7] mentioned another salt-related product that may be associated with microorganisms: *flos salis*.

> *... apellatur et flos salis in totum diversa res umidiorisque naturae et crocei coloris aut rufi, veluti rubigo salis, odore quoque ingrato ceu gari dissentiens a sale, non modo a spuma. Aegyptus invenit, videturque Nilo deferri.*
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> "Flower of salt" is also a name given to an entirely different thing, with a moister nature and a saffron or red colour, a kind of salt rust; it has an unpleasant smell like that of garum, and it is different from salt, not only from foam salt. Egypt discovered it, and it appears to be brought down by the Nile.

Plinius mentioned it as an ingredient of perfumes and unguents, and he noted that "the best kind of it yields a kind of oily fat for there is, surprising as it may seem, a fat even in salt" (*est enim etiam in sale pinguitudo, quod miremur*). He further stated, "It is adulterated too and coloured by red ochre or usually by ground crockery. This sham is detected in water, which washes out the artificial colour while the genuine is only removed by oil, and perfumers use it very commonly because of its colour" [7]. There has been much speculation about the true nature of *flos salis* as described by Plinius. One hypothesis proposed is that the above-mentioned β-carotene rich halophilic alga *Dunaliella salina* is the source of its color [13], and that the "oily fat" in the salt (*in sale*

*pinguitudo*) may have been glycerol, produced by *Dunaliella* as an osmotic stabilizer to enable the cells to grow at saturated salt concentrations [14]. Unfortunately, we know too little about the properties of the Roman *flos salis* to support this interesting idea.

**References**


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