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Discussion on “Living on the rocks: substrate mineralogy and the structure of subtidal rocky substrate communities in the Mediterranean Sea”

Marie Salgues, Centre des Matériaux de Mines d’Alès (C2MA), Université de Montpellier

Mahmoud Hayek, Centre des Matériaux de Mines d’Alès (C2MA), Université de Montpellier

Jean-Claude Souche, Centre des Matériaux de Mines d’Alès (C2MA), Université de Montpellier

Sylvain Pioch Lagam, Université Paul-Valéry

The present paper provides correlative evidence that the mineralogical composition of rocks may influence marine assemblages in Mediterranean shallow sublittoral rocky habitats. They point out that direct effects on sessile organisms (e.g. macroalgae) may cascade up through the entire community and affect higher trophic levels (e.g. carnivorous fishes). Indeed, in seawater, aggregates, concrete or any natural or artificial substrata quickly become fouled [1–3] Colonization surface can be divided into two main stages, micro-fouling and macro-fouling. They are respectively characterized by the formation of bacterial biofilm on the surface and the adhesion of macro-organisms such as algae, barnacles and larvae (macro-fouling) [2,4,5]. The nature of the substrate strongly acts on material’s bioreceptivity according to the literature [6,7].

Miller and Barimo (2001) found differences in coral recruitment between the cementitious matrix and the aggregates (limestone): coral settlement were higher on the embedded limerock while the cementitious matrix was more covered [8]. Scott *et al.* (1988) highlight differences in marine fauna between limestone and a concrete aggregate [9]. This result is confirmed by the study of Coombes *et al.* (2013) which highlight different colonization be-

tween limestone, granite and concrete in intertidal zones [10]. Chase *et al.* (2016) observed that several marine species demonstrated a preference for the cement matrix rather than granite aggregates [11]. Bavestrello *et al.* (2000) find that some sessile fauna (such as hydroids) have a higher affinity for carbonatic substrates than quartzitic ones [12]. This difference could explain the results of Chase *et al.* (2016). However, the inhibiting role of quartz is probably due to both oxidant properties of the quartz crystal surface, generating silicon-based radicals, and formation of OH- radicals in the surrounding aqueous environment [12]. Consequently, a comparative study of bioreceptivity between different building materials such as marbles, limestones, ignimbrites, and bricks in a Mediterranean marine environment was carried out by Aloise *et al.* (2014). Marble and limestone samples, submerged since the 4th century AD, showed intense colonization mainly by boring sponges. Ignimbrites, in the same location, presented a lower biological attack caused by serpulids and bryozoans. In bricks, paste with volcanic aggregates was less bioreceptive, showing a greater resistance to biological colonization, than with quartz [13].

However most of the algae biota, for instance, are not influenced by the mineralogical nature of the rock and, once developed, operate a “biological conditioning” of the substrate, which has been considered as the most important factor structuring faunal communities [12]. Chen *et al.* (2015) reported a negative impact of carbonate precipitation and stated that the leaching rates of concrete should be kept as small as possible because carbonates can cover the surface of concrete, which delays the growth of marine organism [14]. At contrary, Hayek *et al.* (2020) show that carbonated concrete is more bioreceptive than non-carbonated concrete in the first days of immersion [15,16], which is consistent with the study of Hsiung *et al.* (2020) [17]. The nature of the aggregates, integrated into the concrete, does not seem to have a significant influence on the concrete bioreceptivity [18]. However, if they are on the surface, their nature influences the biocolonization of the material [19].

The effect of the substrate mineral composition on the bioreceptivity can be explained by the surface alkalinity of the rocks before and after immersion. In geology, a rock is said to be acidic if it contains more than 63% silica, but the pH of its surface, and surrounding fluid, equilibrate after contact [20]. Indeed, the ability of a material to be colonized by living organisms is dependent by the chemical composition of the surface [21–24] and especially the pH [25,26]. “Low pH” substrate close to the seawater pH (around 7.5) are more favorable to colonization by biofilms or by macrophytes [7,15]. Hayek *et al.* (2020) conclude that the surface pH influences the kinetics and the extent of the development of the bacterial biofilm and could have an influence on the biocolonization quality in the marine environment (biodiversity). However, after two weeks of immersion, the effect of the chemical composition smooths out, according to the study by Jakobsen *et al.* (2016) [27].

Moreover, the rocks can provide nutriment to microorganisms and the mineral composition of the substrate evolve with the biofilm development at its surface [28,29]. In addition, seawater contains micro- and macro-nutrients essential for the growth of the cells of living organisms. Macro-nutrients such as carbon (C), phosphorus (P), nitrogen (N), and silicon (Si), provide the nutritive requirements indispensable to the metabolic functions of living organisms. Micro-nutrients, such as iron (Fe), Zinc (Zn), copper (Cu) or manganese (Mn), while consumed in much lower quantities, act as enzyme cofactors for metabolic reactions [30]. However, some rocks contain nutrients essential to microbiota development [31]. Petrographic analysis should be done before and after colonization by microorganisms.

The physico-chemical properties of the surface also strongly impact the biocolonization of the material [32,33]. These properties include roughness [25,34], porosity [25,35,36] and hydrophobicity [22,37–39]. Several researchers have shown in natural environments and in the laboratory that a more complex and varied surface (in terms of porosity and roughness) is more favorable to the adhesion of micro- and macro-organisms (favorable habitat). This effect can be explained by the availability of nutrients in the interstices and by the presence of shelters for organisms of different size [5,40–43].

Indeed, hydrophilic microorganisms attach more easily to hydrophilic surfaces while hydrophobic microorganisms prefer hydrophobic surfaces [44]. Note that the hydrophobicity and the charge of the surface depend on the chemical composition of the materials. According to several studies, this composition influences the type and diversity of colonizing organisms [38,39]. Despite the importance of this parameter on marine biodiversity as well as on the biocolonization of submerged support, studies which link the surface hydrophobicity of cementitious materials and biocolonization in the marine environment seem to be non-existent to date. Hayek *et al.* (2020) demonstrated in the laboratory that the biocolonization of the surface increases the hydrophobicity and could thus improve the durability of the material by decreasing the absorption of seawater containing aggressive agents [16]. Once the biofilm is attached to the surface, it modifies the physicochemical properties such as the pH and hydrophobicity of the surface which can then facilitate the adhesion of other organisms such as fungi, microalgae, macroalgae and invertebrates, thus forming a biofouling [45,46].

By the end, with this commentaries letter from Guidetti *et al.* (2004), we would like to stress that recent research showing that marine assemblages in rocky habitats are influenced not only by the mineralogical composition but also by the physicochemical properties of rocks.

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