A NOTE ON THE TRAVERTINES OF SUIO, ROCCAMONFINA, WITH REFERENCE TO THEIR MICROBIAL COMMUNITIES AND GEOCHEMICAL ORIGINS

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INTRODUCTION

Deposits of calcium carbonate forming in springs and streams are termed travertine (Julia, 1983) and were exploited as a building material in Rome (lapis tiburtinus of Vitruvius). Travertines are widespread in regions containing carbonate rocks and an abundant supply of water, and are well represented in Italy where at least 100 sites have been documented (Manfra et al., 1976; Pentecost, 1995a). Deposition normally results from the equilibration of bicarbonate-rich groundwater with the atmosphere:

\[ \text{Ca}^{2+} + 2\text{HCO}_3^- \rightarrow \text{CaCO}_3 \text{ (travertine)} + \text{CO}_2 + \text{H}_2\text{O} \]

Aquatic plants colonise illuminated travertines and the unusual physico-chemical conditions result in a specialist flora. Since plants also remove CO₂ during photosynthesis, they have often been implicated in travertine deposition (Ford & Pedley, 1992).

Most of the Italian sites are inactive but there is clear evidence of their association with Quaternary hot springs (Chafetz & Folk, 1984). Active sites are less common but appear throughout Italy, often in areas of recent tectonic activity (Pentecost, 1995b). An understanding of modern travertine formation allows interpretation of older deposits and provides valuable insights into microbial mineralization in hot spring environments (Renaut & Jones, 2000).

Terme di Suio is situated on the Garigliano River, 20km SSE of Cassino and straddles Campania and Lazio. The site consists of 12 thermal springs aligned along two faults trending approximately NW and NE. The faults separate a thick series of Mesozoic limestones and dolomites to the west from the leucite and alkali-trachyte lavas of Roccamonfina Volcano. Roccamonfina caldera is about 20 km in diameter, and was active 630-53 ka (Caprano et al., 1992). The site was brought to our attention by Prof. R. Barbieri and the travertines do not appear to have been previously investigated, though the associated thermal waters are well known (D’Amore et al., 1995, Duchi et al., 1995). Travertine is deposited at four springs as cascades or mounds and locally covered with colourful algae.

We aim here to provide a brief description of the Suio travertines, their geochemical origins and the associated photosynthetic microorganisms.

METHODS

Water samples were taken at four travertine-depositing spring vents in glass bottles and duplicate samples analysed within 3h for total CO₂ and pH. Alkalinity corrections for CO₂ were made for sulphide, borate and reactive-silicate. Major cations were determined on acid-preserved samples using methods previously described (Pentecost, 1992). Stable carbon and oxygen isotope analyses were determined on SrCO₃ precipitated in situ from springwater using ammoniacal SrCl₂. Free CO₂ gas was also collected and adsorbed in a pure KOH solution. Analyses were performed with a VG Optima dual-inlet gas source mass spectrometer with external precision ± 0.07‰ and are reported as VPDB. Algal samples and fresh travertines were preserved in CaCO₃-saturated 1% glutaraldehyde and returned to the laboratory for examination.

RESULTS AND DISCUSSION

Travertine setting and morphology

Water, gas and travertine sampling locations are shown in Fig.1. All sites were situated close to the Garigliano River and consisted of small mounds, slopes and cascade deposits. Travertine was deposited immediately below thermal outfalls, all of which were artificial or modified for the provision of water for the Terme. The most extensive deposits occurred on the riverside below Term Tomassi, consisting of a series of steep cascades 5m in total height. They were fed by intermittent effluent at a temperature of ca. 30°C. The next largest is a travertine mound situated about 50 m west of Vasco degli Inferne. Water at 58°C issued from a well pipe at...
about 1 l/sec and formed a travertine mound, 3 m high and 16 m wide, immediately below (Fig. 2). This location appeared to be nameless so we termed it CG Spring. About 500 m to the SE on the same side of the river is another piped source with water at 53°C forming travertine crusts in the water channel below. We named this site “AD spring”. A small quantity of travertine was also sampled from the sides of the hot water reservoirs at Terme Ciorra, 520 m south of Terme Tomassi. Travertine also occurred in the watercourse at Terme S. Egidio further north but we did not sample this site. At all sites the travertine was of high purity and consisted of calcite. At CG spring most of the calcite occurred as poorly laminated subhedral microspar (crystal diameter 20-30 µm) and irregular rhombohedra producing a massive, powdery fabric. Small vugs were surrounded by calcite scalenohedra. The mass included occasional vertically-arranged “feather crystals” 1.5 mm long (cfr. Fig. 5 in Guo & Riding, 1992). At Terme Tomassi the travertine forming along the side of a reservoir and consisted entirely of large feather crystals up to 5 mm long. The crystals were not closely associated with the overlying algal mats, which contained sparse irregular patches of micrite.

Gas and Water Geochemistry

The thermal waters were highly mineralised and contained large quantities of dissolved CO₂ (Table 1). All springs contained traces of oxygen (resazurin positive) possibly from surface water contamination, along with H₂S (ca 0.2 mmol/L). The chemical composition of these waters is similar to other thermal Italian springs such as the Viterbo group and Rapalano Terme near Siena which deposit much travertine (Guo & Riding, 1992). Previous measurements of CO₂ at Tomassi and Ciorra (D’Amore et al., 1995) gave values similar to those reported here, but their Ca values were higher than ours.

Stable isotope composition demonstrated enrichment of the travertine with $^{13}$C ($\delta^{13}$C 7.68-7.96 ‰). Similar enrichments are known from other Italian travertines such as those of Tivoli (Manfra et al., 1976). The CO₂ emissions at Aqua Salamone and the Bridge site (Fig. 1) were also slightly enriched ($\delta^{13}$C + 0.59 ‰ and +0.96 ‰ respectively). Equilibrium fractionation of this gas with precipitated calcite should give a $\delta^{13}$C of ca. + 8 ‰ for the travertine, close to the observed values. Carbonate rocks subjected to contact metamorphism undergo decarbonation leading to $^{13}$C enrichment of the resulting CO₂ (Turi, 1986) and this has been used to explain the occurrence of $^{13}$C-enriched travertines throughout Italy. The same process may explain the Suio travertines although the $\delta^{13}$C of the source carbonate is unknown. If the CO₂ emissions at Aqua Salamone and Bridge result directly from decarbonation, the parent limestones must be slightly depleted in $^{13}$C over marine limestones, unless further water-rock interactions have occurred en route to the surface. Oxygen isotope compo-
sitions of the travertine (Table 1) are more difficult to interpret due to probable water-CO$_2$ exchange but the values are typical of other Italian travertines originating from thermal springs (Fritz, 1965; Manfra et al., 1976). While Roccamonfina volcano does not appear to provide a magmatic contribution to the thermal springs at Suio (Duchi et al., 1995), deep faults exist along the course of the Garigliano River and most likely provide an easy passage to the surface for gases forming at depth.

**Associated microorganisms**

A limit flora occurred on the travertines (Table 2). The flora was dominated by a narrow (0.4-1.0 µm diameter) filamentous cyanobacterium *Phormidium laminosum* which occurred as highly coloured (deep green to orange) strata at the travertine surface. It formed blue-green strands in the hot flowing water at temperatures of 43-53°C but only became abundant when water temperature fell below 48°C. On cooler areas of the CG spring mound, where algae were kept moist by capillarity, the orange form became conspicuous (Fig. 2). This may be due to production of carotenoid UV-protective pigments in areas where growth is retarded by reduced water availability. *P. laminosum* is a well known hot-spring cyanobacterium which is abundant on the Viterbo travertines (Pentecost, 1995c). The coccoid cyanobacterium *Synechocystis minuscula* was abundant at Terme Tomassi. This organism has not been previously recorded from travertine. Few diatoms occurred, the most abundant being *Achnanthes minutissima* and *Nitzschia frustulum*. The occurrence of diatoms at 48°C is notable as few species have been previously found at this temperature, which is high for diatoms (Stockner, 1967). Overall, the flora was limited in extent with 10 species recorded, possibly the result of dissolved sulphide inhibiting the growth of other algae. In some travertines, a close association has been found with certain algae and the deposition of calcite (Viles & Goudie, 1990) but this was not observed at Suio, so the participation of algae in depositing the Suio travertines is unlikely to be significant.

**ACKNOWLEDGEMENTS** - We are grateful to the owners of Terme Ciorra and Terme Tomassi for permission to sample. Thanks also to Dr. B. Spiro for undertaking the stable isotope analyses.

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### Tab. 1 - Suio thermal spring chemistry.

<table>
<thead>
<tr>
<th>Determinand</th>
<th>AD spring</th>
<th>CG spring</th>
<th>Terme Ciorra</th>
<th>Terme Tomassi</th>
</tr>
</thead>
<tbody>
<tr>
<td>temperature °C</td>
<td>52.90</td>
<td>57.80</td>
<td>63.00</td>
<td>55.00</td>
</tr>
<tr>
<td>pH</td>
<td>6.41</td>
<td>6.48</td>
<td>6.78</td>
<td>6.55</td>
</tr>
<tr>
<td>TDIC* mmol/L</td>
<td>38.20</td>
<td>41.80</td>
<td>32.80</td>
<td>40.30</td>
</tr>
<tr>
<td>Ca mmol/L</td>
<td>4.13</td>
<td>6.66</td>
<td>4.29</td>
<td>5.16</td>
</tr>
<tr>
<td>Mg mmol/L</td>
<td>3.50</td>
<td>2.40</td>
<td>3.10</td>
<td>3.40</td>
</tr>
<tr>
<td>TDIC δ13C ‰</td>
<td>7.68</td>
<td>7.96</td>
<td>12.03</td>
<td>-11.37</td>
</tr>
<tr>
<td>TDIC δ18O ‰</td>
<td></td>
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</tbody>
</table>

*Total dissolved inorganic carbon

### Tab. 2 - Suio travertine: photosynthetic microorganisms.

<table>
<thead>
<tr>
<th>Genus/Phylum</th>
<th>species</th>
<th>nomenclature</th>
<th>CG spring 35°C</th>
<th>CG spring 44°C</th>
<th>CG spring 48°C</th>
<th>Terme Tomassi 30°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyanobacteria</td>
<td>Calothrix</td>
<td>parietina</td>
<td>Thuret</td>
<td>X</td>
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<tr>
<td></td>
<td>Chroococcus</td>
<td>helveticus</td>
<td>Naeg.</td>
<td>X</td>
<td>X</td>
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<tr>
<td></td>
<td>Phormidium</td>
<td>incrustatum</td>
<td>(Naeg.) Gom.</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phormidium</td>
<td>laminosum</td>
<td>Gom.</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
</tr>
<tr>
<td></td>
<td>Schizothrix</td>
<td>cf pulvinata</td>
<td>(Kuetz.) Gom.</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Synechocystis</td>
<td>minuscula</td>
<td>Woronich.</td>
<td>XX</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diatoms*</td>
<td>Achnanthes</td>
<td>minutissima</td>
<td>Kuetz.</td>
<td>19</td>
<td>34</td>
<td>35</td>
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<tr>
<td></td>
<td>Navicula</td>
<td>cf. pupula</td>
<td>Kuetz.</td>
<td>11</td>
<td>2</td>
<td>3</td>
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<tr>
<td></td>
<td>Nitzschia</td>
<td>frustulum</td>
<td>(Kuetz.) Grunow</td>
<td>67</td>
<td>64</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>Nitzschia</td>
<td>sp.</td>
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</table>

X scarce ; XX frequent
* Percent relative abundance based on 500 counts except CG where based on 100

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REFERENCES


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