MICROBIAL, ALGAL, AND FUNGAL STRATEGIES FOR MANGANESE
OXIDATION AT A SHADE TOWNSHIP COAL MINE, SOMERSET
COUNTY, PENNA.¹

by

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Abstract. Successful designs to eliminate Mn from mine discharge are necessary for both restoring
abandoned mine lands and permitting the mining of high sulfur coal in the eastern United States.
A passive in-line system that meets Mn discharge limits was built at the discharge from the former
Shade Township coal mine in south central Pennsylvania. Qualitative research on monthly
changes in the microbial and algal community that removes Mn is underway. Epilithic attachment
of microorganisms was analyzed on artificial (glass microscope slides) and natural substrates
(limestone thin sections) that were immersed in surface water for one month periods over 6
months. Organisms attached to both glass and limestone substrates. Limestone became coated
with 34-86 % more Mn than did glass surfaces. Light microscopy revealed 12 different strategies
are being used by bacteria, cyanobacteria, diatoms, green algae, and fungi to oxidize Mn. The
dominant method used by the epilithic community to oxidize Mn is coating of holdfasts by the
iron bacterium, Leptothrix discophora, and the green alga, Ulothrix sp. Other methods for Mn
removal by oxidation include coating of individual cells, filaments/sheaths/hyphae, extracellular
polysaccharides, and biofilms. The unplanned community at the site is multifaceted and
extremely efficient in its Mn removal ability. Community interactions or complexity may play
roles in the stability of the ecosystem and the efficiency of its Mn oxidizing ability.

Introduction

Mn in the form of Mn²⁺ is highly soluble in acidic and near-neutral conditions (Hem, 1985),
which means that the regulated coal-mining industry must use chemical treatment to meet Mn discharge
limits (Kleinmann and Watzlaf, 1988). Finding inexpensive passive treatment methods remains an
important objective for government and industry (Robbins, 1998), particularly for abandoned coal
mines in Pennsylvania and West Virginia. Several studies have shown that limestone is an effective and
inexpensive substrate for passively removing Mn (Brant and Ziemkiewicz, 1997; Hedlin et al., 1994; Sikora et al., 1996; Watzlaf, 1997).

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The mechanism of manganese removal by
oxidation is thought to be dominantly biological, and
the details of biological removal can be elucidated at
different scales. Phillips et al. (1995) analyzed the
relationship from a macroscopic scale and showed
that a mixed community of cyanobacteria, algae, and
bacteria can be quite efficient in its Mn-removing
capability. Robbins et al. (1992) used light
microscope analysis on Mn-oxide growths on silicate
cobbles and showed that one bacterium, Leptothrix
discophora, dominated Mn-oxide precipitation. Vail
et al. (1988) isolated Mn-oxidizing bacteria from a
limestone remediation pond and showed that they
were highly efficient when inoculated into buried
limestone drains. At the angstrom scale level, many
studies including Gliesby and Ehrlich (1992) have
shown the specific sites of Mn attachment to bacterial
sheaths. Stone (1997) detailed 8 physiological
strategies used by bacteria that interact with the Mn
cycle.

The technology to isolate strains and adapt
them to local conditions is quite expensive (Vail and
Riley, 1995). However, the success of their studies
and of Phillips et al. (1995) suggests that more
studies are needed. In particular, microscopic data

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might reveal useful information about community interactions that may play a role in the stability of the limestone ecosystem and the efficiency of its Mn oxidizing ability.

A passive in-line system that meets Mn discharge limits was built at the discharge from a former Shade Township coal mine in south central Pennsylvania, Somerset County, 7 km southwest of Windber, PA (N40°10.574' lat., W78°52.094' long.) (Williams et al., 1996). Following cessation of mining of the Upper Kittanning coal bed in 1982, anoxic limestone drains (ALDs) were built at seeps; these drains are removing Al and raising alkalinity. Discharge next flows through a cattail-dominated wetland that is removing Fe but lowering pH. Discharge then flows over two limestone cells that are removing Mn. The first limestone cell is composed of a bed of limestone cobbles; the bed is 0.6 to 1.2 m thick and 20 m by 20 m in width. The cell started precipitating Mn within one month of completion in 1990, and came into compliance within 15 months. In the Brant and Ziemkiewicz (1997) data set, which covered from December, 1991 to March, 1994, streamflow from the wetland averaged 19 L/min (5 gal/min). pH averaged 7.8. At the first limestone cell, influent Mn was around 25 mg/L; with the exception of the month of June, effluent Mn consistently met EPA regulations for Mn concentration <2 mg/L (Brant and Ziemkiewicz, 1997).

We designed a set of experiments to analyze seasonal changes in biological processes that are precipitating oxidized Mn on the limestone. Epilithic attachment, which is fixation to solid surfaces, was the major focus of this research. Epilithic attachment of bacteria, algae, and fungi was analyzed on artificial (glass microscope slides) and natural substrates (two limestone varieties). Limestone samples from the Shade site and from the Action site nearby in Meyersdale, PA, were prepared commercially as thin sections. Macrophytes were collected periodically and analyzed microscopically to assess epiphytic attachment, which means attachment to plant surfaces.

**Materials and Methods**

**Chemistry.** Water samples were analyzed quarterly using ASTM standard D858-95 for Mn content. In addition, following Morgan and Stumm (1965), orthotoluidine was used to test for the presence of oxidized Mn on slides and organic structures.

**Biology.** Microscopic evaluation of the dominantly aerobic microscopic community in a shallow water column was the major focus of our studies. Epilithic attachment that resulted in Mn oxidation was analyzed monthly on artificial (glass microscope slides) and natural substrates (two limestone varieties). Limestone samples from the Shade site and from the Action site nearby in Meyersdale, PA, were prepared commercially as thin sections. Macrophytes were collected periodically and analyzed microscopically to assess epiphytic attachment, which means attachment to plant surfaces.

**Results and Discussion**

**Site Characterization**

During the course of study, water levels fluctuated at the site, but limestone cobbles were usually submerged under approximately 10 cm of water. Submerged limestone cobbles are individually coated with a very densely interwoven, 1-cm-thick brown/black cyanobacterial mat that includes Oscillatoria sp. In places, the mat is continuous but sags at the junctions between individual cobbles. The green alga, Ulothrix sp., attaches to the mat using holdfasts and its long filaments float in the sag pools. These filaments do not become coated with brown/black Mn oxide. The base of the mat, where attached to limestone, is colored white from calcite crystal precipitation. When cobbles are exposed by falling water levels, the mat dehydrates into thin sheets that curl up and peel off the cobbles, thereby exposing the dark gray color of the underlying limestone.

The limestone cell, which could also be called a shallow pond, is open to full sunlight. Cattails have encroached along the pond edges and are beginning to colonize dried out patches of limestone. The mat does not grow where cattails cast shadows.

**Chemical Environment**

The average pH of the Shade site was 7.8 in the 6 months of observation (Table 1). The water temperature was close to that of ambient air temperature because the water column is so shallow. Specific conductance averaged around 972 µS/cm at the outflow. Dissolved Mn values for inflow and outflow show that the limestone cell efficiently
removed Mn from the water with the exception of May and July (Table 1).

Oxidized Manganese on Epiliths

The organisms at the Shade site are using a wide variety of strategies for oxidizing Mn (Table 2). These include coating of cells, filamentous sheaths, holdfasts, and secreted substances. Bacteria, cyanobacteria, fungi, and algae perform one or more of each of these processes. The character of Mn oxidation by the organisms using these strategies shifted during the experiment (Table 3). During the 6-month study, almost every organism precipitated oxidized Mn, but at varying amounts. During the spring and summer, slides were more coated than those collected during the fall.

Cell coatings. Individual bacterial cells were completely coated, giving the impression that the bacteria became entombed in the oxide coating. This process was seen on both cocci and rods. Diatoms also became coated, but the coating appeared to be random because not all individuals were coated on the same slides.

Filament/sheath/hypha coatings. Individual bacterial filaments/sheaths, fungal hyphae, and algal filaments became lightly to strongly coated with oxidized Mn.

Holdfast coatings. In terms of total Mn precipitation, by far the dominant Mn oxidation process was by coatings on holdfasts, which are attachment structures, of the iron bacterium, Leptothrix discophora, and the green alga, Ulothrix sp. L. discophora holdfasts averaged around 5 µm in diameter, whereas those of Ulothrix sp. were 20 µm or larger. Holdfasts of the bacterium also colonized cattail stems, turning submerged plant surfaces brown/black, whereas holdfasts of the alga colonized moss leaves and stems. Holdfasts were the dominant method of Mn oxidation in the early spring (Table 3). L. discophora holdfasts are typically abundant on cobbles in swiftly moving water (Robbins et al., 1992), and were not expected in the slowly moving water of the Shade site. The Ulothrix sp. holdfasts are similar to those seen downstream from a chemical remediation site in West Virginia (Robbins et al., 1997).

Extracellular polysaccharide (EPS). EPS are substances secreted by organisms; many EPS have metal oxidizing capabilities (Fletcher and Floodgate, 1973; Puchelt et al., 1973). Bacterial holdfasts, fungal hyphae, and algal filaments and holdfasts were surrounded by brown/black substances that attach to compounds that have been excreted by the cells. EPS oxidation was most extensive during the summer months (Table 3).

Biofilms. The glass slides became coated with biofilms that turn black/brown from oxidized Mn. The biofilms were enmeshed with bacterial rods or cocci. These are typical structures formed by epilithic bacteria (Little et al., 1997).

Oxidized Manganese on Macrophytes and Cyanobacteria

Clumps. At the Shade site, only one strategy for Mn oxidation was evident among the macrophytes and cyanobacteria. Entwined filaments of Mn oxidation were evident among the macrophytes and cyanobacteria. Entwined filaments of Mn oxidation were most extensive during the summer months (Table 4). Ulothrix precipitated Mn as brown/black clumps.

The clumps of oxidized Mn are similar to those found by Richardson et al. (1988), on colonies of cyanobacteria in Oneida Lake, NY. At that site, microelectrodes were used to show that pH elevation during photosynthesis was the cause of Mn oxidation.

Oxidized Manganese on Limestone Thin Sections

Oxidized Mn on limestone thin sections followed the same pathways as on glass surfaces (Table 3). Coatings on cells, filaments/sheaths/hyphae, holdfasts, EPS, and biofilms all contained oxidized Mn. The bacteria, fungi, and algae on the limestone appear to be the same species/morphotypes as on the glass surfaces (Table 3). The difference between the two substrates was in amount of oxidized Mn precipitated. Point-count transects across slides showed that between 34 and 86% more oxidized Mn precipitated on limestone.

The two different limestone varieties being used in this experiment had different types and amounts of oxidized Mn coatings. The variety being used at Shade became more coated than the variety being used at the Action site in Meyersdale. No effort was made to learn more about the sources and chemistry of the limestone varieties, but this casual observation confirms other findings that the limestone variety is an important factor in remediation designs.
Conclusions

Oxidized Mn is being precipitated by many organisms in the water column at Shade. Bacteria, cyanobacteria, fungi, diatoms, and green algae are participating in the process, and at least 12 different strategies are being employed by these organisms to oxidize and therefore eliminate Mn from the water column. The strategies include coating on individual cells, filaments/sheaths/hyphae, holdfasts, EPS, and biofilms. While both glass and limestone surfaces are colonized by Mn oxidizing organisms, more Mn is being precipitated by the epilithic community on the limestone surfaces. Macrophytes and cyanobacteria also have strategies for precipitating Mn, but the process is related to photosynthetic pH elevation and the oxidized Mn is in the form of external clumps. Mn oxidizing bacteria also colonize macrophytes, forming coated holdfasts that color the plant tissues brown/black.

The fact that this unplanned community came into existence and continues to function, grow, and meet discharge limits is very significant. It suggests that local organisms which can handle elevated Mn may be universally present. It confirms the findings of Phillips et al. (1995) that a mixed community of cyanobacteria and algae is very efficient in its Mn-oxidizing capability. They showed that it was possible to manipulate different components to increase efficiency without knowledge of specific details. Our data supplements theirs by explaining some of the interacting processes that are occurring at a microscopic level.

The microscopic analysis shows that Mn which coats EPS is common and the amount increases in the warmer months; it is not presently known what factors initiate EPS excretion. Holdfasts of bacteria are efficient in the spring and holdfasts of algae are efficient in the warmer summer months. Ecological studies are particularly needed on the green alga, Ulothrix, because its Mn-oxidizing holdfasts are large. This ecological study of the former Shade coal mine is important because Mn removal met discharge limits within 15 months of construction and has operated with few failures for the past 8 years.

Acknowledgments

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Literature Cited


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Table 1. Chemical characteristics of Shade Township site water samples (Abbreviations: nd, no data; ORP, oxidation-reduction potential).

<table>
<thead>
<tr>
<th>Sample date</th>
<th>pH influent</th>
<th>pH effluent</th>
<th>Temperature influent (°C)</th>
<th>Temperature effluent (°C)</th>
<th>Specific conductance influent (µS/cm²)</th>
<th>Specific conductance effluent (µS/cm²)</th>
<th>ORP (mv)</th>
<th>Mn influent (mg/L)</th>
<th>Mn effluent (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/6/98</td>
<td>nd</td>
<td>7.8</td>
<td>nd</td>
<td>20</td>
<td>nd</td>
<td>1080</td>
<td>-39.1</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>4/21/98</td>
<td>6.3</td>
<td>7.6</td>
<td>11</td>
<td>13</td>
<td>800</td>
<td>620</td>
<td>nd</td>
<td>10.2</td>
<td>0.1</td>
</tr>
<tr>
<td>5/26/98</td>
<td>6.2</td>
<td>7.4</td>
<td>13</td>
<td>17</td>
<td>895</td>
<td>772</td>
<td>nd</td>
<td>12.9</td>
<td>2.9</td>
</tr>
<tr>
<td>6/26/98</td>
<td>6.6</td>
<td>7.7</td>
<td>12</td>
<td>20</td>
<td>837</td>
<td>663</td>
<td>nd</td>
<td>11.1</td>
<td>0.3</td>
</tr>
<tr>
<td>7/21/98</td>
<td>7.3</td>
<td>8.0</td>
<td>16</td>
<td>21</td>
<td>943</td>
<td>776</td>
<td>nd</td>
<td>12.5</td>
<td>3.8</td>
</tr>
<tr>
<td>8/28/98</td>
<td>7.7</td>
<td>8.2</td>
<td>16</td>
<td>26</td>
<td>1,200</td>
<td>797</td>
<td>nd</td>
<td>12.2</td>
<td>0.3</td>
</tr>
<tr>
<td>9/4/98</td>
<td>nd</td>
<td>7.87</td>
<td>nd</td>
<td>28.4</td>
<td>nd</td>
<td>338</td>
<td>nd</td>
<td>14.5</td>
<td>0.2</td>
</tr>
<tr>
<td>9/9/98</td>
<td>7.3</td>
<td>8.2</td>
<td>13</td>
<td>18</td>
<td>1,160</td>
<td>763</td>
<td>nd</td>
<td>12.2</td>
<td>0.3</td>
</tr>
<tr>
<td>9/16/98</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>1200</td>
<td>196</td>
<td>nd</td>
<td>nd</td>
</tr>
</tbody>
</table>

Table 2. Strategies used by microorganisms to oxidize Mn (EPS=extracellular polysaccharide).

<table>
<thead>
<tr>
<th>BACTERIA</th>
<th>CYANOBACTERIA</th>
<th>FUNGI</th>
<th>ALGAE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating cells (rods, cocci)</td>
<td>Lumps on entwined filaments</td>
<td>Coating hyphae</td>
<td>Coating filaments</td>
</tr>
<tr>
<td>Coating filaments/sheaths</td>
<td>Coating EPS</td>
<td>Coating diatom frustules</td>
<td></td>
</tr>
<tr>
<td>Coating biofilm</td>
<td>Coating Leptothrix discophora holdfasts</td>
<td>Coating EPS</td>
<td></td>
</tr>
<tr>
<td>Coating EPS</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Macroscopic biological data and chemical characteristics at Shade Township site (Symbols: see Table 3; ls, limestone).

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Sample type</th>
<th>Collection date</th>
<th>pH</th>
<th>Temp. (°C)</th>
<th>Brown clumps</th>
<th>Other information</th>
</tr>
</thead>
<tbody>
<tr>
<td>SH-1</td>
<td>algal mat</td>
<td>4/6/98</td>
<td>7.8</td>
<td>20</td>
<td>+++</td>
<td>microcrustaceans</td>
</tr>
<tr>
<td>SH-2</td>
<td>white filaments on algal mat</td>
<td>4/6/98</td>
<td>7.8</td>
<td>20</td>
<td>+++</td>
<td>---</td>
</tr>
<tr>
<td>SH-3</td>
<td>black suspension</td>
<td>4/6/98</td>
<td>nd</td>
<td>nd</td>
<td>+++</td>
<td>reducing bacteria and black sulfides on microcrustacean fecal pellets</td>
</tr>
<tr>
<td>SH-4</td>
<td>green algae</td>
<td>4/6/98</td>
<td>7.8</td>
<td>20</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>SH-6</td>
<td>black scrape from ls</td>
<td>4/6/98</td>
<td>nd</td>
<td>nd</td>
<td>+++</td>
<td>---</td>
</tr>
<tr>
<td>SH-11</td>
<td>brown on cattail</td>
<td>4/6/98</td>
<td>nd</td>
<td>nd</td>
<td>---</td>
<td>Ulotrih colonizes moss</td>
</tr>
<tr>
<td>SH-12</td>
<td>brown on moss</td>
<td>4/6/98</td>
<td>nd</td>
<td>nd</td>
<td>---</td>
<td>brown color from brown plant hairs</td>
</tr>
<tr>
<td>SH-13</td>
<td>algal mat on ls</td>
<td>7/7/98</td>
<td>nd</td>
<td>nd</td>
<td>+++</td>
<td>brown filaments colonize mat</td>
</tr>
<tr>
<td>SH-14-1</td>
<td>algal mat on black limestone</td>
<td>9/4/98</td>
<td>7.87</td>
<td>28.4</td>
<td>+++</td>
<td>brown filaments colonize mat</td>
</tr>
<tr>
<td>SH-15</td>
<td>surface of mat</td>
<td>9/4/98</td>
<td>7.00</td>
<td>24.0</td>
<td>+++</td>
<td>brown filaments colonize mat</td>
</tr>
<tr>
<td>SH-15B</td>
<td>base of mat</td>
<td>9/4/98</td>
<td>7.53</td>
<td>26.1</td>
<td>---</td>
<td>white color from calcite crystals</td>
</tr>
<tr>
<td>SH-19</td>
<td>microbial mat</td>
<td>9/16/98</td>
<td>7.35</td>
<td>28.1</td>
<td>+++</td>
<td>brown filaments and brown hyphae in mat</td>
</tr>
</tbody>
</table>

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Table 3. Microscopic biological data and chemical characteristics (Explanation of symbols: --, absent, +, 1 on slide; ++, 1 every field; +++; 2-4 every field; ++++, 5 or more every field) (Abbreviations and symbols: bn, brown; dk, dark; gn, green; lt, light; med, medium; EPS, extracellular polysaccharide)

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Substrate</th>
<th>Submersion dates</th>
<th>Brown holdfasts of Leptothrix discophora</th>
<th>Brown cocci (co) or rods (r)</th>
<th>Brown coated bacterial filaments or chains</th>
<th>Iron bacteria</th>
<th>Colored biofilms</th>
<th>Brown coated fungal hyphae</th>
<th>Brown holdfasts of Ulothrix</th>
<th>Brown coated algal filaments</th>
<th>Leaking brown EPS</th>
<th>Diatom species (brown-coated)</th>
<th>Brown coated animals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>glass</td>
<td>4/6/98-5/6/98</td>
<td>++++</td>
<td>co, sr, mr</td>
<td>+ filaments</td>
<td>---</td>
<td>lt bn</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>---</td>
<td>6 (bn)</td>
</tr>
<tr>
<td>3-4</td>
<td>glass</td>
<td>5/6/98-6/5/98</td>
<td>++++</td>
<td>co, sr</td>
<td>+++ filaments</td>
<td>L. discophora</td>
<td>lt med bn</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>4 (bn)</td>
<td>---</td>
</tr>
<tr>
<td>5</td>
<td>Action limestone</td>
<td>5/6/98-6/5/98</td>
<td>++++</td>
<td>co, sr</td>
<td>+ filaments</td>
<td>---</td>
<td>med bn</td>
<td>+</td>
<td>+</td>
<td>---</td>
<td>---</td>
<td>3 (bn)</td>
<td>---</td>
</tr>
<tr>
<td>6</td>
<td>Shade limestone</td>
<td>5/6/98-6/5/98</td>
<td>++</td>
<td>sr, co</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>+</td>
<td>+</td>
<td>---</td>
<td>---</td>
<td>3 (bn)</td>
<td>---</td>
</tr>
<tr>
<td>7-8</td>
<td>glass</td>
<td>6/5/98-7/7/98</td>
<td>++++</td>
<td>sr</td>
<td>+ filaments</td>
<td>Siderocystis</td>
<td>med bn</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+++</td>
<td>3 (bn)</td>
<td>---</td>
</tr>
<tr>
<td>9</td>
<td>Action limestone</td>
<td>6/5/98-7/7/98</td>
<td>+</td>
<td>co, sr</td>
<td>---</td>
<td>---</td>
<td>med-dk bn</td>
<td>+</td>
<td>+</td>
<td>---</td>
<td>---</td>
<td>3 (bn)</td>
<td>---</td>
</tr>
<tr>
<td>10</td>
<td>Shade limestone</td>
<td>6/5/98-7/7/98</td>
<td>+</td>
<td>co, sr</td>
<td>+ filaments</td>
<td>+++</td>
<td>---</td>
<td>+</td>
<td>+++</td>
<td>---</td>
<td>---</td>
<td>2 (bn) coated ostracod</td>
<td>---</td>
</tr>
<tr>
<td>11-12</td>
<td>glass</td>
<td>7/7/98-8/11/98</td>
<td>++</td>
<td>sr, co</td>
<td>++ filaments</td>
<td>Siderocystis</td>
<td>med bn</td>
<td>--</td>
<td>++</td>
<td>---</td>
<td>+++</td>
<td>3 (bn)</td>
<td>---</td>
</tr>
<tr>
<td>13</td>
<td>Action limestone</td>
<td>7/7/98-8/11/98</td>
<td>+</td>
<td>sr</td>
<td>++ filaments</td>
<td>Siderocystis</td>
<td>med bn</td>
<td>--</td>
<td>++</td>
<td>---</td>
<td>+++</td>
<td>2 (bn)</td>
<td>---</td>
</tr>
<tr>
<td>14</td>
<td>Shade limestone</td>
<td>7/7/98-8/11/98</td>
<td>+</td>
<td>sr, co</td>
<td>+++ filaments</td>
<td>med bn</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>+++</td>
<td>---</td>
<td>2 (bn) coated ostracod</td>
<td>---</td>
</tr>
<tr>
<td>18</td>
<td>Shade limestone</td>
<td>8/11/98-9/4/98</td>
<td>+</td>
<td>sr, co</td>
<td>+ filaments</td>
<td>---</td>
<td>+</td>
<td>+</td>
<td>+</td>
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<tr>
<td>19-20</td>
<td>glass</td>
<td>9/4/98-10/16/98</td>
<td>++++</td>
<td>sr, co</td>
<td>++ filaments</td>
<td>med bn</td>
<td>+</td>
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<td>coated micro-crustacean</td>
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<tr>
<td>25-26</td>
<td>glass</td>
<td>10/16/98-11/18/98</td>
<td>+</td>
<td>co, sr</td>
<td>++ filaments</td>
<td>L. discophora</td>
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<td>6 (bn)</td>
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<tr>
<td>27</td>
<td>Action limestone</td>
<td>10/16/98-11/18/98</td>
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<td>co, sr</td>
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<tr>
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<td>Shade limestone</td>
<td>10/16/98-11/18/98</td>
<td>+</td>
<td>co, sr</td>
<td>+ filaments</td>
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