We report field observations of drill cores from the "Bunte Breccia" deposits, which constitute ≈90% of all impact breccias beyond the crater rim of the Ries, Germany, a 26 km diameter impact structure (1). These deposits are composed of Triassic and Mesozoic sediments derived from the upper section of the Ries target and of Miocene marine (OMM) and freshwater lake (OSM) sediments (e.g., 1,2,3). Prior to the Ries event a cliff line striking EW (Fig. 1) marked the northernmost invasion of the Miocene sea and its unconsolidated sands. Most of the Miocene fresh water deposits can also be excluded from the crater cavity. The presence of these Miocene sediments in "Bunte Breccia" is therefore evidence for the incorporation of materials from terrain outside the crater cavity ("local" materials). Fig. 1 illustrates the distribution of Bunte Breccia and location of drill sites; Table 1 lists pertinent geologic and topographic data for the cores obtained. Locations 1-5 represent a radial traverse; locations 6-11 provide information about lateral variations of Bunte Breccia at various, maximum radial ranges.

FIELD OBSERVATIONS: The cores consist of megaclasts (>1 m grain size) clasts (1-100 cm) and matrix (<1 cm). "Megaclasts" in excess of 10 m of both local and crater derived sources were encountered but local components dominate (Fig. 2). Most megaclasts are undeformed and primary sedimentary textures display different dip angles from clast to clast, indicating a jumbled, irregular configuration of megaclasts. "Clasts" (1-100 cm grain size) display also irregular orientation and consist of crater derived and local components, with the local contributions again dominating. Absolute clast frequency is variable as well as grain size and proportion of crater/local materials. Clasts may be undeformed (e.g., soft sands and clays) but commonly extremely deformed, twisted and contorted geometries are in close spatial proximity. The "matrix" (<1 cm grain size) contains abundant clastic material up to 1 cm grain size and a fine grained groundmass of clays and sands of predominantly (if not exclusive) local derivation. The clastic materials represent the entire array of Ries lithologies, though grain size distribution, lithologic make up and absolute frequency may vary. The relative proportions of megaclasts, clasts and matrix are variable and no distinct pattern or trend can be established based on the 10 locations studied. Also neither crater derived nor local materials display concentration trends towards the top or bottom of any given profile.

Breccia matrix varies not only between localities but also within a given profile, as evidenced by different color shades, variable grain size, proportion of clay and sand components and various populations of discrete clasts (.1-1cm). Matrix variations occur on a scale on the order of a few m, though variations on smaller and larger scales are also present. The transition from one matrix to another is either gradual (over ≈1 dcm) or abrupt (<1 cm). Most frequently, different matrix types are separated in the core by megaclasts, with the character of the matrix remaining fairly homogeneous between such clasts.

All core materials were inspected for laminar versus turbulent flow during emplacement using criteria such as preferred alignment of clasts, lineations in
SHALLOW DRILLING IN THE "BUNTE BRECCIA"

F. Horz et al.

the matrix, flow pattern in soft clays or noncohesive sands, etc. Indications for a turbulent environment dominate because of the matrix's "massive" texture, lack of lineation, irregular orientation of clasts of all sizes and highly contorted deformation structures in clay clasts.

"Breccias within breccias" are commonly observed, including multiple "generations" (up to 3). These features together with the various matrix types indicate an extremely efficient, multiphase mixing process which repeatedly recycled and mixed all components. Mixing occurs on large (>10 m) and small (<1 mm) scales and is extremely intense. Clay clasts lodged in a sand host (or vice versa) are taken as evidence for very energetic mixing requiring high particle velocities in order to penetrate each other.

The contact of Bunte Breccia and authochtonous country rock (mostly unconsolidated sands or soft clays) is in most cases exceptionally sharp, i.e., <1 cm in dimension (localities 2,3,4,6,10,11); all other transition zones were <50 cm. The underlying substrate materials are undeformed because small scale primary sediment structures are perfectly preserved and horizontal. The lack of any weathering horizon at the top of the country rock indicates erasure of the old land surface.

An attempt was made in the field to estimate the percentage of "local" versus crater derived materials. However, even crude estimates are difficult to make because of the relative fine grained and therefore poorly defined matrix, which constitutes typically >50% of the cores. Present field estimates indicate that local components S of the cliff line may vary from 50 to 80% and cores number 7 and 10 may even contain ~90% local materials; there is no doubt that local materials vastly dominate the breccia character at the larger ranges (sites 7,8,9,10,11).

CONSTRAINTS ON EMBLACEMENT MECHANISM:
1. The total thickness - on occasion >100 m - of the Bunte Breccia containing very large amounts of local components necessitates a process that is capable of excavating the local terrain outside the crater rim to depths measured in tens of m, on occasion even >50 m.
2. The contact relationships with in situ materials imply that the debris surge was deposited on top of a newly excavated datum plane, rather than on top of an old land surface.
3. Various matrix types and their style of occurrence suggest that they were transported to their final resting place as distinct polymict breccia "megaclasts".
4. "Breccias within breccias" and especially the different matrix types indicate a thorough, multiphased, mixing and brecciation process, in which both crater derived and local materials participate with the same intensity.
5. Evidence for both relatively energetic forces (e.g., clays lodged in sands) and modest energies (underformed primary textures in clast) is in such close spatial association that a mixing process with dramatically varying particle velocities is necessitated.
6. The irregular and seemingly random orientation of clasts of all sizes together with the "massive" character of the matrix indicate a largely turbulent environment.

These constraints are consistent with a ballistic ejecta mode of emplacement. The large amounts of energy required for excavating local materials, for
SHALLOW DRILLING IN THE "BUNTE BRECCIA"

F. Horz et al.

the intense and thorough mixing and for final emplacement by a debris surge is supplied by ballistic ejecta (4,5). Recent observations (6) do not constitute evidence against such an emplacement mechanism, as they indicate only the existence of a debris surge, but not its mode of formation.

<table>
<thead>
<tr>
<th>Drill Location</th>
<th>Range 1 (km)</th>
<th>Azimuth (°N)</th>
<th>Thickness of Bunte Breccia (m)</th>
<th>In Situ Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28.5</td>
<td>194</td>
<td>&gt;15</td>
<td>OSM</td>
</tr>
<tr>
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<td>25.5</td>
<td>196</td>
<td>52</td>
<td>OSM</td>
</tr>
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<td>19</td>
<td>136</td>
<td>74</td>
<td>Upper Jurassic Lime</td>
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<td>115</td>
<td>47</td>
<td>Upper Jurassic Lime</td>
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<td>OSM</td>
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<td>OSM</td>
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<tr>
<td>10</td>
<td>27</td>
<td>104</td>
<td>64</td>
<td>OSM</td>
</tr>
</tbody>
</table>

1^Range: From crater center (crater radius, r* = 13 km). 2^No contact; drilling terminated in Bunte Breccia for a variety of geological and economic reasons.

References:
2. Gall H. et al. (1975) Geologische Rundschau 64, 915-947.

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