Up From Below: Upper crustal xenoliths as indicators of underlying bedrock in scoria cone deposits

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Abstract: Analysis of upper crustal xenoliths in a scoria cone on the flanks of Akaroa Volcano provides a stronger understanding of the underlying bedrock in the region. A dissected scoria cone on the eastern flanks of Banks Peninsula provides a cross-sectional view of the internal features of a scoria cone. The xenoliths deposited within a scoria cone correlate with the uppermost layers of bedrock due to wall-rock rip-off in the conduits of shallow plumbing systems. Thin section analysis of these samples from cone deposits suggests that the uppermost formation underlying Akaroa is dominantly quartz-rich, tan-grey sandstone, with some volcanic interbeds. Sedimentary units found in outcrops in Lyttleton Harbour contain similar sandstone lithologies based on past geologic mapping. A literature study of scoria cones, as compared to field observations, suggests a Strombolian style eruptive sequence that correlates with the rock type found in the xenoliths. A schematic cross-section has been developed based on rock type, stratigraphic correlation and scoria cone plumbing systems.
Introduction: An understanding of the bedrock underlying a volcano gives a further comprehension of the overall regional geology as well as the plumbing system beneath the volcano (Valentine, 2012; Valentine and Groves, 1996). However, exposures can be rare or non-existent, as they are around Akaroa volcano on Banks Peninsula, New Zealand. In cases like this, upper crustal xenoliths in deposits from small monogenetic, flank volcanoes such as scoria cones can serve as a window to the bedrock (Valentine, 2012). Determining the lithologies of the underlying bedrock and the regional stratigraphic sequence provides details of the regional geology and processes occurring in shallow, subsurface, volcanic plumbing systems.

The Akaroa Volcanic complex, Banks Peninsula, is an extinct, composite, strato-shield volcano active 9.3-8Mya (Hampton, 2010) that composes the entire eastern side of Banks Peninsula (Figure 1). Lyttleton Volcano, to the west, has restricted bedrock outcrops (Sewell, 1988), that provide a basic stratigraphic sequence for the peninsula. The bottom formation of this sequence is the Torlesse Supergroup, a series of greywacke, conglomerates and siltstones that have been highly sheared. The subsequent sequences are layered marine siltstones and sandstones of varying compositions. Above this lies the Allendale rhyolite and the Lyttleton Volcanic complex. No sedimentary bedrock exposures are present on Akaroa volcano but lower to upper crustal xenoliths have been found, dominantly in domes and of mafic composition (Hartung, 2011; Tramanotano, 2012). The scoria cone in Pa Bay is the first to be found with sedimentary upper-crustal xenoliths.

Pa Bay is an eastern bay on Akaroa Volcano (Figure 1). The scoria cone here is excellent for study since coastal erosion has dissected it and left a cross section; with a magmatic source closer inland and the flanks becoming more and more distal seawards (Figure 2a).
Scoria cones studied in the past have been in locations with well-known stratigraphic units. These helped develop a better understanding of the plumbing system. This study reverses this process, by using our understanding of scoria cones to discern the stratigraphy beneath.

Xenoliths are rock fragments found in a different rock formation, typically volcanic or intrusive rocks. The xenoliths found in the scoria cone are generally well preserved, with little melting or metamorphosis and have remained relatively intact. These xenoliths can be used as a proxy for the upper stratigraphic units based on our understanding of scoria cones and their eruptive styles (Kereszturi and Nemeth, 2013; Valentine 2012).

Geologic Setting and Background:

Geologic Setting: Akaroa volcano is a polygenetic volcano with multiple, previously identified scoria cones throughout its flanks. Akaroa and Lyttleton volcanoes are part of the Miocene intraplate volcanic complex that intruded into the late Triassic mudstone, sandstone and chert formations of the Torlesse Supergroup (Hampton, 2010). The highly deformed Torlesse supergroup is seen in relatively restricted outcrops throughout Lyttleton volcano (Sewell, 1988).

The sedimentary outcrops exposed on Banks Peninsula near the Lyttleton crater reflect a marine transgression starting in the late Cretaceous into the Oligocene, dominantly the Eyre Group which includes the Charteris Sandstone, a locally glauconitic, quart-rich sandstone with mudstone beds and trachytic dyke intrusions. A large time gap of no sedimentation occurred, followed by a regression in the Miocene, which deposited the Burnt Hill Group that includes the Bradley sandstone, a quartz-rich graded sandstone (Sewell, 1988; Field and Browne, 1989). This is shown schematically in Figure 3, a stratigraphic diagram of eastern Canterbury.
Methods:

The key methods used in this study are geologic field mapping, sample collection, point count along dissected cones and thin section analysis. Geological mapping was conducted throughout Pa Bay as well as along the scoria cone itself. The dissected cone displays the various facies present following the model of Kereszturi and Nemeth (2012). These facies were mapped using a point count system taken at 9 sites along the cliff face approximately every 10 meters (Figure 4). This included: concentration estimations of matrix, blocks and bombs, lapilli and xenoliths, measurements of the 5 largest clasts, strikes and dips of bedding and photos. Samples of xenoliths as well as scoriaceous deposits were taken from every field site.

The samples were analysed in thin section and hand sample in order to determine rock type and correlate it to regional formations based on past geological mapping of the surrounding area. The data from the point count sampling allowed us to confine the deposits as scoria cones and determine the facies of the entire deposits.

Results:

Field Facies: Figure 5 displays graphically the average point count percentages of matrix, clasts, lapilli and xenoliths per area. In general, the outcrop is dominantly composed of matrix, grading from 50-60% matrix in sites A-C up to 80% in the more distal sites G-I (Figure 4). The matrix is bedded with a generally south strike and the dip steepening towards the more distal zones. The pyroxene lapilli concentration stays generally constant, making up between 10-20% of the deposit. These clasts compose between 10-20% of the overall deposit in locations closer inland (Locations A-E) and 5% in more distal locations (F-I). Clast size
also dominantly grades outward, with the most distal locations also having the smallest clasts. The largest clasts in a location are often found in 1-2 meter thick clast rich layers, rather than evenly distributed throughout the outcrop. Xenoliths compose the smallest percentage of the deposit, between ~1- 5% across the outcrop. Figure 6 shows a typical field deposit.

Hand Sample and Thin Section Results:

Matrix: The matrix is composed dominantly of a very fine grained, red ash with large amounts of calcium carbonate secondary precipitant. It is pyroxene rich (most likely augite) with olivine and potassium feldspars, which are all often euhedral, but occasionally broken, and some microlite growth (Figure 7a, 7b). There are also occasional very small, very fine grained, quartz-rich clasts (only visible in thin section). The matrix composition does not change throughout outcrop.

Pyroxene lapilli: Pyroxene lapilli are singular medium-large (up to 50mm) pyroxene crystals not imbedded in the matrix (Figure 8).

Basaltic clasts: Various basaltic clast rich layers of vesicle rich blocks and bombs (Figure 6), as well as large areas with occasional blocks and bombs are found throughout the deposit. These clasts are red to black in colour and have a similar composition to the matrix. The largest clast size measured was 250mm and they occasionally contain carbonate precipitant in their vesicles.

Xenoliths: There are several types of xenoliths present in the deposit: sandstones, basaltic lavas and a presently unidentified igneous rock. Full sample descriptions can be found in Table 1.

- Sandstones: Sandstones are the most common xenolith type found in the deposit. There are some differences between the samples, but all are dominantly fine-very fine grained, white and pink to tan, and quartz rich (Figures 9-11).
• Lava Flows: There are several examples of xenolithic lava flows—distinguished from the blocks and bombs by their lack of vesicles and distinctive appearance in thin section (Figure 12).

• Mafic igneous rock: There are a limited number of plagioclase feldspar (~70%) and pyroxene (~30%) rich, crystalline rocks with porphyritic-phaneritic texture. These rocks show secondary alteration (Figure 13).

Discussion:

Scoria cones are differentiated from maars, spatter cones and tuff cones by eruptive style, morphology and size. Maar-diatreme and tuff cones are dominated by phreatomagmatic eruptive phases and wide craters (with respect to their overall width) that are prone to collapse. Spatter cones are generally smaller in width than scoria cones and typically have a Hawaiian style eruptive sequence with large amounts of spatter (welded or unwelded), blocks and bombs and very little ash deposit. Scoria cones, on the other hand, are characterized by ash and spatter deposits along the flanks with welded spatter deposits near the crater (Figure 14) (Kereszturi and Nemeth, 2012). These parameters allow us to define the monogenetic cone in Pa Bay as a scoria cone, rather than a maar, spatter or tuff cone.

Scoria cones are made up of a range of volcaniclastic, eruptive material: from lava rocks, to breccias, to lapilli and ash with areas rich in blocks and bombs as well as xenoliths (Kereszturi and Nemeth, 2012). These layers change with distance from vent and eruptive style. Figure 14 is a schematic diagram of a typical scoria cone. Note specifically, the plumbing system of the cone—with feeder dykes bringing magma up from depth with minor groundwater additions and sequential phreatomagmatism beneath the cone. These dykes feed into the cone, causing Strombolian style or phreatomagmatic eruptions, whose level of violence is based on gas segregation in the conduit. This violence affects the amount of
country rock xenoliths ejected and where within the conduit they come from (Kereszturi and Nemeth, 2013, Di Traglia et al. 2009). The mechanics behind the entrainment and ejection of the xenoliths is dependent on multiple factors and varied, including shear stress exertion by magma flow, explosive magma-water interactions and capture by offshoot dykes, as well as many others (Valentine and Groves, 2009). Phreatomagmatic eruptions will typically be more xenolith-rich than the less energetic Strombolian phases since they do not have as much time to sink and dissolve into the magma column (Vespermann and Schmincke, 2000).

Strombolian phases of eruptions, which are typical in this type of scoria cone, are less energetic than phreatomagmatic and allow more time for wall rock to sink and melt into the magma. This melt is reflected in the matrix—which contains very small, quartz rich sedimentary clasts throughout it. This is also the reason why there are so few xenoliths within the deposit, and why most of them likely come from the uppermost stratigraphic levels. Rocks pulled from lower stratigraphic levels have more time to mix with the magma and therefore are less likely to erupt in a small scoria cone, while rocks from higher stratigraphic units are more likely to be found in deposits since they have less time to mix and melt into the magma.

Figure 2b is a schematic interpretation of the scoria cone in Pa Bay based on the geological mapping done. The blue area represents an intrusion (currently under research), the red indicates an area of proximal scoria deposits with characteristic welded spatter deposits (currently under research). The orange zone is the main area of focus for this study and consists of the media flank deposits of the cone. This is supported by the point-count study, which illustrates how the matrix becomes a larger component (and clasts a smaller component) with distance from the proximal zone (Figure 5).
The xenoliths within the scoria cone deposit in Pa Bay make a small percentage of the overall composition but have very important indications for what lay beneath the volcano during formation. Scoria cones have a shallow, dyke fed plumbing system and studies done in areas of known stratigraphy have seen correlations between xenoliths and the formations found in the top 100-150m of underlying basement rock (Valentine, 2012, Valentine and Groves, 1996). Therefore, we can assume that the xenoliths found in the deposit are from this upper region. The only basement rocks exposed in Banks Peninsula are found in Lyttleton harbour and consist over several different sedimentary sequences ranging in age from late Cretaceous to Miocene (Sewell et al 1988; Field and Brown 1989). Figure 3, as mentioned before, shows the stratigraphic units exposed in that area in cross section form. Towards the northeast edge of known exposures, the Allendale rhyolite appears to thicken, while directly below it is the Bradley Sandstone. The Bradley sandstone is part of the Burnt Hill Group and consists of pale grey-white, well sorted fine quartz sandstone that grades up to a poorly-sorted medium to coarse quartz sandstone. In thin section, it consists dominantly of quartz (80-90%) and sedimentary rock fragments (10-15%) (Sewell, 1988). The Burnt Hill Group in other locations in Canterbury shows these sedimentary rocks interbedded with basaltic flows and volcaniclastic rocks (Forsyth et al 2008). The quartz-rich sandstone is the closest correlation to the xenoliths in this study; the Charteris bay sandstone is also similar, however it is well sorted and contains glauconitic and mudstone interbeds, which are not present in the xenoliths found.

The schematic cross-section of the basement rock underneath the scoria cone (Figure 15) was developed based on a combination of the known stratigraphic outcrops, an understanding of a typical scoria cone’s shallow plumbing system and thin section analysis of the samples found. As shown, the zone of xenolith entrainment extends into some of the lower lithologies but magma stalling and lack of energetic eruptions leads to mixing and melting of these xenoliths.
before they reach the surface. The conduit widens as it reaches the top 100 to 50 meters below the surface, allowing for increased friction and entrainment along the side walls (Valentine and Groves, 1996).

Not included in the cross section are the mafic igneous xenoliths. They are most likely from a similar magmatic phase as the scoria cone itself and there is no literature on a source. They are similar in composition, but not in texture, to enclaves found in Goat Rock (Bertolett, in publication; Tramontano, 2012). It is unclear the exact origin of these xenoliths, but they do indicate an intrusive, mafic body that cooled before being integrated into volcanic processes. This could, in future studies, give a better indication of the magmatic system beneath Akaroa Volcano.

**Future Work:** This study is the beginning of a potentially much larger study. In order to draw a more exact cross-section and understanding of the bedrock, the sample size would have to be much larger, in order to get an equal representation of all xenoliths. Work is currently underway to better understand the overall magmatic systems at work in Pa Bay and combining these works in future studies would greatly increase the understanding of the Pa Bay scoria cone. The mafic intrusive xenoliths also potentially provide a larger story of the volcanic magmatic system. Geochemical analysis on those would be useful to expand this understanding.

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Figures

Figure 1: Simplified geologic map of Banks Peninsula, with the field site, Pa Bay, highlighted. The area labelled as “pre-Lyttleton Volcano” is the location of the sedimentary outcrops found on Banks (adapted from Hampton, 2010).

Figure 2a: Panoramic photo of eastern side of Pa Bay. The center of the photo is the field site of this study.

Figure 2b: Interpretated facies of the deposits, based on field research and photo study: (A) crystal-rich intrusion, (B) proximal welded scoria deposits, (C) fall-dominated medial scoria deposits (main study area), (D) conglomerate. The white dashed line estimates the vertical extent of the scoria cone deposits that are then overlain by loess. Black dashed lines trace out apparent dips in scoria deposits, indicating the likely central vent location.
Figure 3: Field and Browne’s (1985) cross sectional schematic diagram of the stratigraphy of eastern Canterbury (left side) and Banks Peninsula (right side). Bradley Sandstone and Charteris Bay Sandstone are highlighted as possible xenolith protoliths.

Figure 4: Annotated photo of Pa Bay scoria cone with field locations noted, as well as strikes and dips taken from those locations. The intrusion and distal zones mark either end of the field study area.
Figure 5: Field area highlighted with pie graphs showing the average proportions of matrix, lapilli, clasts and xenoliths. Note how the percentage of matrix increases with distance from vent location, resulting in the cross-sectional outcrop.

Figure 6: Field photo of typical outcrop. Highlighted are the sandstone xenolith, the relatively large pyroxene lapilli and the volcanic clasts. Note that the outcrop is dominated by matrix and that volcanic clasts are dominantly found in a single bed, with occasional outliers.
Figure 7a: Hand sample of groundmass, note the red color of the ash dominated matrix as well as some of the larger crystals that are visible with the naked eye. The white material on the left is secondary carbonate precipitant.

Figure 7b: Photomicrograph of matrix, with large, broken pyroxene crystal in XPL. The matrix is ash dominated and vesicular with carbonate secondary precipitant and no visible grains. Pyroxene, olivine and feldspar crystals were common throughout, often times fractured.

Figure 8: Hand sample of large, single-crystal, pyroxene lapilli that are commonly found throughout the deposit, making up 20% in places.
Figure 9: Hand sample photo of xenolith (sample 7A). The xenoliths throughout the outcrop are embedded into the cliff wall, making them difficult to remove. However, note the lack of mixing between the matrix and the xenolith.

Figure 10: Photomicrograph of a sandstone xenolith (sample 2.2) in XPL. Note the subangular-subrounded grains, which are dominantly quartz with occasional plagioclase feldspars.

Figure 11: Photomicrograph showing the edge between quartz-rich sandstone and groundmass in XPL. The sandstone is very fine grain, quartz rich with sub-angular to subrounded grains while the groundmass in dominantly ash with a large, fracture olivine crystal. Note the lack of mixing between the two, which is typical of all xenoliths analysed.
Figure 12: Large, very crystal poor, dense massive lava flow. In thin section, there are some phenocrysts present but there is an overriding, dominant linear trend in the minerals.

Figure 13: Photomicrograph of mafic igneous rock in XPL. Note the large, interlocking plagioclase crystals with distinctive twinning and pyroxene (most likely augite) crystals. Secondary alteration is common throughout the rock.
Figure 14: Annotated cross-section of a typical scoria cone. Note specifically the flank deposits, which correlate with the scoria cone deposit in the study and are shown to be dominantly ash to block spatter, while more proximal zones contain welded or agglutinated spatter. The plumbing system consists of one main feeder dyke and minor groundwater mixing, exacerbating wall rock rip-off. Adapted from Kereszturi and Nemeth, 2013.

Figure 15: Schematic, simplified diagram of the bedrock underlying the Pa Bay scoria cone. The highlighted area denotes the xenolith entrainment zone, based on Valentine (2012). Due to the relative low energy of Strombolian style eruptions, xenoliths from the lower facies are more likely to mix and melt into the magma, while upper formations spend less time mixing. The lithologies and their depths were taken from Field and Brown (1989). It is concluded that most xenoliths are from the upper most sandstone layer- the Bradley Sandstone Formation, of the Burnt Hill Group.
### Table 1: Description of all xenolithic thin sections

<table>
<thead>
<tr>
<th>Number</th>
<th>Site</th>
<th>Description</th>
<th>Thin Section Description</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>B</td>
<td>A white clast with some small grey clasts that has no reaction to HCl</td>
<td>Very hard to identify most due to difficulty cutting, but what was identifiable was approximately 50% rounded, medium grained quartz crystals and 50% quartz rich rock fragments with very fine grained, well rounded quartz crystals. There is also a small amount of an opaque mineral throughout the sample.</td>
<td>Sandstone</td>
</tr>
<tr>
<td>2.2</td>
<td>B</td>
<td>White, fine grained quartz rich sandstone surrounded by red, ashly, crystal rich matrix</td>
<td>90% sub-angular to subrounded, poorly sorted quartz grains and quartz rich, very fine grained matrix, 5% fine grained feldspars and 5% very fine grained, quartz rich rock fragments. There is limited mixing or melt between xenolithic and continuous matrix.</td>
<td>Sandstone</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>Very fine grained, pink cherty xenolith with some small opaque minerals. Conchoidal fracture patterns are present</td>
<td>Too fine grained for identification</td>
<td>Chert</td>
</tr>
<tr>
<td>7A</td>
<td>H</td>
<td>Pink, fine grained sandstone</td>
<td>95–96% very fine grained, sub-angular subrounded, “mashed” quartz crystals whose matrix is over-written by calcium carbonate precipitate. There is some minor mixing between spongy matrix and xenolith around edges.</td>
<td>Sandstone</td>
</tr>
<tr>
<td>5A</td>
<td>I</td>
<td>Tan-grey, very fine grained, quartz rich sandstone</td>
<td></td>
<td>Sandstone</td>
</tr>
<tr>
<td>8.2</td>
<td>I</td>
<td>Tan-grey, fine-grained, quartz rich sandstone with some small grey clasts.</td>
<td>Very fine grained with similar “mashed” look and large amounts of secondary carbonate precipitate. Quartz crystals are sub-angular to sub-rounded with some small quartz-rich clasts.</td>
<td>Sandstone</td>
</tr>
<tr>
<td>1</td>
<td>A</td>
<td>Dense, basaltic, lava flow clast</td>
<td>Augite and olivine rich flow with some microcline feldspar in a fine-grained, microcline rich ground mass. The groundmass is too fine-grained to identify crystal content. The phenocrysts are medium sized and originally euhedral but are now often broken</td>
<td>Lava Flow</td>
</tr>
<tr>
<td>5.3</td>
<td>E</td>
<td>Very crystal poor lava flow with occasional highly weathered pyroxenes and olivines.</td>
<td>In thin section, flow is very fine grained and highly weathered with a fine-grained ground mass with “stung out” augite crystals and occasional feldspars and small opaque minerals throughout</td>
<td>Lava Flow</td>
</tr>
<tr>
<td>3.2</td>
<td>C</td>
<td>White and black, crystalline xenolith</td>
<td>Dominantly (70%) plagioclase feldspar with 30% pyroxene, probably augite, with an interlocking crystalline texture. Crystals have a porphyritic-plagioclase texture, with multiple sizes of crystals present. There is secondary alteration present in the feldspar and pyroxene.</td>
<td>Mafic Inclusion</td>
</tr>
<tr>
<td>3.3</td>
<td>C</td>
<td>Pink and white, crystalline xenolith with black crystals in a discrete linear pattern</td>
<td>Very similar to sample 3.2, being rich in plagioclase feldspar and pyroxene and the fine art texture is difficult to discern.</td>
<td>Mafic Inclusion</td>
</tr>
</tbody>
</table>
### Table 2: Field site notes and hand and thin section descriptions

<table>
<thead>
<tr>
<th>Field Site</th>
<th>Overall Composition</th>
<th>Bedding</th>
<th>5 largest clasts (mm)</th>
<th>Photo</th>
<th>Hand Sample</th>
<th>Thin Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>69% red ash matrix, 15% cobble size, pyroxene-rich, vesicular basaltic clasts, 20% pyroxene lapilli, 5% feldspar lapilli, 1% xenolith</td>
<td>21E dip, S strike</td>
<td>116, 120, 119, 260, 120</td>
<td>419, 420</td>
<td>0</td>
<td>305: 1. augite and olivine-rich flow with some microcline feldspar, phenocrysts medium sized and often broken, groundmass too fine-grained for crystal content but microcline rich</td>
</tr>
<tr>
<td>B</td>
<td>50-60% red matrix, 15-20% py lapilli (up to 40mm), 15-20% basaltic clasts, 3% xenoliths, 5% feldspar lapilli—Beds more crystalline clast rich</td>
<td>220, 120, 100, 190, 250 (7)</td>
<td>421</td>
<td>2-: white, fine grained, ashy sandy (sandstone)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>50-60% matrix, 15% clasts, 20% pyroxene lapilli, 5% feldspar olivine lapilli, 3% xenoliths (30mm)</td>
<td>180/24E, 70, 70, 90, 100, 100 (xenolith 65)</td>
<td>422</td>
<td>3-: ground mass sample, red ash matrix with pyroxene lapilli, ash clasts, carbonate infill, black (pyroxene) crystals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>10% lapilli/cobble basaltic clasts, 50-60% matrix, 15% pyroxene lapilli, 20% secondary calcium carbonate precipitate, 4% xenoliths</td>
<td>120, 70, 80, 105, 70</td>
<td>423</td>
<td>4-: pyroxene lapilli clasts, up to 5cm for one crystal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| E          | Dominantly matrix, with yellow altered layer above, two clast rich layers, some beds crystalline resistant, 15% pyroxene lapilli, 15-30% precipitate (bottom to top), 10% cobbles, 5% xenoliths, 60% matrix | 198/24E, 130 (f), 210 (f), 220, 180 (f), 200 (f)—all from same clast rich bed | 425 | 5-: 5a-522 5b-523 5c-523 | 5.2-: ashy block with large vesicles that have secondary calcite infill, some edges are crystalline rich (pyroxene, olivine—same as Atwood 19
| P | 66% red matrix, 5% basaltic cobbles (red) flattened at bottom to more clast rich at top, pyroxene lapilli up to 20mm, 2% xenoliths | 178/30 | 200, 250, 260 (f), 100 (d), 150 (f) -- are along bedding planes | 5.3. Very fine grained, highly weathered with "string out" augite and occasional feldspar. Very small opaque mineral found throughout. | 329 |
| G | 70-80% matrix, 2% red/brown and vesicular clasts, 10% pyroxene, 1% xenoliths | 180/20E | 90, 100, 110, 70, 75 | 6.-- cleat; very smooth pink xenolith with some black tiny minerals (too small to tell) very fine grained, well cemented, conchoidal fracturing on sample. | 332 |
| H | 86% red matrix, 15-20% pyroxene lapilli (becoming smaller 5-10mm), 5-16% clasts, 3% xenoliths | 80, 110, 100, 80, 160 | 7a-- calcareous sandstone, pink, some small black minerals, fine grained, fizzes with HCl. | 7A: 95% quartz grains, very fine grained, subangular to sub rounded with same "mashed" look, birefringence very low sometimes undulose extinction, matrix overwrittten with calcium carbonate precipitate, with some minor mixing between matrix and xenolith around edges. | 333 |
| I | 70-80% matrix, 18% black lapilli, 5% clasts, 3% xenoliths | 155/40E | 80, 70, 40, 90, 65 | 8.-- groundmass with some type of red reworked bomb type thing, ground mass is pyroxene and olivine rich with secondary calcareous stuff. | 337 |
|  |  |  | 8a-- calcareous sandstone, sandy material. Tan, very fine grained xenolith, a larger lathic (grey), mod sorted, fizzes with HCl. | 340 |
|  |  |  | 8.2.-- fine grained quartz sandstone with some calcareous material. Tan grey similar to sample 8a, some small grey lathic. | 341 |

Atwood 20