Hornfels artifact sourcing by instrumental neutron activation analysis (INAA) in the Karoo region of South Africa

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The text of this presentation is given in the notes and can be seen by clicking on Notes Page in the View menu.
This is going to be about our search for a method for sourcing stone artifacts made by Bushman hunter-foragers who lived in the high, semi-desert plateau of central South Africa.
The predominant rock type used for toolmaking throughout this region was hornfels.

It’s an metamorphic rock that outcrops in myriads of small patches, often no larger than an office desk. This is a really large one, and that’s all Acheulian quarry debris in the foreground.
Of no economic value, hornfels outcrops are omitted from all published geology maps, and are chronically understudied.

So we set out to map all the outcrops in this area, and ......
.... recorded some 1600 of them. Over 90% were quarried at some time in prehistory. When we consider that the same area contains another 15,000 lithic scatters, ranging in age from the Acheulian up to historic Bushmen (all made lithics of hornfels) the potential here becomes obvious. If we can find some way to source hornfels tools to their parent outcrops, then we can reconstruct past movements of artifacts around the landscape. That in turn would allow us to study intangibles such as prehistoric foraging ranges around sites, and maybe even territorial boundaries, and exchange networks -- and we could do this all the way back to the Acheulian. With its unique geological configuration, covering many many thousands of square kilometers [and you are looking at just five thousand of them here], the Karoo region offers enormous potential for such studies.
But can we source the hornfels?  
As a first test-bed, we chose this part of the mapped area – a circle of 15 km diameter, containing just 39 hornfels outcrops, and centered on a well documented rockshelter.
which was packed with plenty of hornfels tools.
The shelter is on the flank of one of the many ridges that criss-cross this typical piece of treeless, Karoo landscape.
Those ridges are vertically intrusive dolerite dikes -- more resistant to weathering than the softer surrounding shales and sandstones. That sheet of dolerite in the southeast is a horizontal sill, now weathered to a swarm of low rocky hills. The whole is intersected by a network of minor vertical dikes, most of them no more than a meter wide, or high.
The intrusive dolerite literally bakes the shale in small patches on either side, so the hornfels crops out randomly in small “aureoles” along the edges of the dikes, and (rarely) on top of sills.
Here’s a typical section through an aureole
With time, the dolerite erodes, and the hornfels stands proud of the surface – as we saw in that opening photo.
Eventually, the aureole itself is reduced to a residuum of rubble chunks, covered with a thick, reddish brown oxidation rind. These, too, were quarried in the past.
Most sources in our study were residual rubbles, so sampling became rather a potluck business
We aimed for 20 samples per outcrop, but some were so small that we opted for less. At one sprawling residuum, nearly a hectare in size, we were forced to go for 40 samples to get proper coverage. We also selected 300 artifacts from the shelter, marked x in the center.
Now let’s look at the geochemistry of a single outcrop.

Here’s the Instrumental Neutron Activation Analysis output for six trace elements (in ppm), and five majors (in percentages) for 20 rock samples from the same outcrop.

As you can see, elements vary quite a lot within single outcrops.
That means that values between outcrops tend to overlap on a massive scale. Here we see the outer ranges for two other outcrops overlain in pink and in red.

First, we ran a Discriminant Analysis on the whole database to see if neighboring outcrops would chemically group into swarms. No element or element combination could be singled out as a useful marker by which to identify outcrops, or groups of neighboring outcrops.

DA is widely held to be the most appropriate statistical method for obsidian source-tracking, and it clearly won't work here.
So, we turned next to Principal Component Analysis. Using a value called the Z-score (which avoids the numerical dominance of majors over traces), PCA searches for closely related specimens, and groups them into clusters. The PCA grouped the database into 88 clusters, each containing a handful of artifacts, plus the mix of outcrop samples that most resembles them. Twenty-two clusters contain only mixtures of outcrop specimens with *no matched artifacts at all*. This map shows us how much of each outcrop matches NO artifact. So it highlights those outcrops that received less attention from the stone knappers at the shelter.

Not shown here, but also of interest are another 11 PCA clusters containing ONLY artifacts (many of these “clusters” are just single artifacts). This is really helpful. The PCA has isolated 14 artifacts that match no quarry in the study area. Given the thoroughness of our outcrop sampling, we suspect they were brought in from outside our circle – in other words they are of non-local origin.
That leaves us with 55 clusters that pair off artifacts with a mix of outcrop specimens. For example, these four artifacts were placed by the PCA in Cluster 8. Note that they share rough *proportions* of positive (red) and negative (green) z-scores, but note also that the bottom set of scores has larger absolute values than the others.
Now comes trouble. These are the outcrop samples that go with those four artifacts -- 20 rock samples from 13 outcrops, from all over the study area. The artifacts could have come from any one of these. Although PCA has narrowed down our options (compared to DA), we’ve reached its limits as a sourcing tool.
So, we are forced to explore unconventional methods. Eventually we settled on an outmoded approach, which nevertheless produces coherent results. Here, we sum the z-scores of each tool in Cluster 8 (ignoring the plusses and minuses) and have done the same for one of the rock samples (in purple). as a demo.
Now we subtract the z-scores of each artifact from its equivalent value in the rock specimen (this time, paying close attention to those plusses and minuses) and sum the differences. Note how the fourth tool now differs a great deal from the rock sample.
And here, we repeat the same exercise using Euclidian distances instead of arithmetic differences – another trick used to suppress the dominance of too-high values. This shows the overall geochemical “proximity” of each tool to the rock sample.
These are the proximity scores of that first flake compared to every rock sample in the test area. Outcrops are listed down the left, with the Cluster 8 outcrops darkened. Numbers of rock specimens are across the top, standardized to 20. Those red bars count rock samples with proximity values less than 2, meaning they closely resemble the flake. Pink values are less that 3, and are more distant from the flake. While the flake could conceivably have come from any outcrop with a red bar, it matches many more specimens from just one outcrop (black arrow), so there’s a far better chance that the flake came from there.
On this map, red circles replace those red bars, and the ‘most-likely’ outcrop is highlighted.

The outcrops in pale blue also have rock specimens in PCA Cluster 8.
The next artifact on the list clearly favors a neighboring outcrop
But the third tool favors both, with only a slight bias towards one, which is two samples ahead of its rival. Overall the three tools have a strong affinity for this quite specific part of the map.
More trouble ahead. The fourth artifact in Cluster 8 has all pink bars, and short ones at that. Note however, that they are slightly longer in darkened lanes, which is where the tool gets its affinity with Cluster 8. But with no red bars at all, it’s not really close to any rock sample in the whole study area. Perhaps it has a non-local origin, and became attached to Cluster 8 by chance, thanks to its shadowy resemblance. Or it might really belong, and only looks weak because we haven’t sampled enough of the relevant outcrops.

Whatever the answer, it won’t give us its most-likely source. And that goes for another 30 tools that fail to match with their assigned cluster.
And we have to jettison another 90 tools that match up in this way. It’s a respectable member of its cluster [its red circles fall nicely on most blue dots] but no one outcrop really stands out because red-bar samples are so few, wherever we turn. These tools look more like ghosts of the real thing. Actually there are a few more PCA clusters that contain only ghosts.
So, when we set aside all the unmatched ones, all the ghosts, plus another 30 tools that were good matches but had two outcrops tied for first place, we are left with this array of ‘most-likely’ outcrops.

They are mapped here as 3-or-more ahead of their rivals (red), 2 ahead (sepia), and dubiously just 1 ahead (the fringes of latté).

Very pretty, but perhaps we are just whistling in the dark. To find out we decided to have a closer look at the context of the artifacts.
The tools come from the trench inside the shelter overhang, and from another in the talus slope outside.

That’s a collapsed stone wall under the shelter drip-line, and those outside loops are dry-stone livestock enclosure walls, built on the talus slope.
Here’s the basic stratigraphy inside the shelter – a preceramic lens at the base;
   pottery arrives around 100AD; there’s a hiatus, then livestock herders settle in the vicinity (orange);
   they go away, and stockless hunter-foragers use the place for a short while (white again),
   then the Dutch trekboers, advancing from the south, reach this area. The Bushmen survive somehow by slipping in and out of service with three adjacent Dutch stock farms, until well after AD 1850 (the yellow).
Flakes were taken from a dense column of horizontally stratified lithics concentrated under the drip line, and endscrapers of various designs come from a wider field.
Material was removed in 12 very thin spits each about 2-3 cm thick. Hornfels artifacts in the topmost, historical levels are rare. By then, the surviving Bushmen – now hemmed in by Dutch farmsteads – were turning to nearby sandstones for material.
Only endscrapers were tested from the bouldery talus. Their positions are projected on to the upslope profile.
In each spit, horizontal positions of artifacts were plotted to the nearest 25x25cm block.

Inside the shelter, the lowermost spit (on bedrock) has these specimens plotted by their PCA cluster numbers. In four cases (pink) same-cluster tools came from adjacent blocks – in fact two Cluster 7s came from the same block. They’re very probably flakes struck from the same core that fell nearby each other. So – while PCA scatters the outcrops throughout the clusters, PCA correctly groups some of the artifacts into clusters.

A weaker case can be made for those three pairs linked by green lines -- because they lie farther apart in the deposit.
The same applies in overlying Spit 10, and so on up the sequence.

Now -- if our scheme for identifying “mostly-likely” outcrops has any merit at all, then flakes in a pink patch *must* come from the same outcrop.

And so should most of the specimens at both ends of a green line.
When we pick through every spit this way, plus the talus, we find 27 such pink patches, of which 8 are spoiled because they contain ghosts and/or no-match specimens.

That leaves us with 19 testable pink patches (each with 2 or more artifacts). Twelve of those (that’s 63%) contained artifacts that were, indeed, affiliated with the same outcrop.
Of the 31 testable green lines, 19 (62%) had the same outcrop at both ends. So, with only a 60% hit-rate, our procedure is anything but perfect, but is probably as good as it’s going to get, given that the test itself is hardly watertight.
There appear to be changes in quarry use through time.

The first occupants (Spit 11, on bedrock) were sharply focused on a single outcrop, and are wholly disinterested in nearby outcrops (in the pink loop). The pattern suggests ephemeral, perhaps overnight visits, after a long day’s march through the veld. If they were making daily excursions from the shelter and returning each night we could reasonably expect more hornfels from nearby outcrops,
In Spit 10 a wider array of outcrops comes into use,
and the pattern holds for Spit 9
and again for Spit 8
Through all this time (Spits 11thru 8), it looks like the shelter was located on the southwest rim of their foraging range, and they seldom ventured upstream from here.
Although not as rich in quarries, that upstream zone was in no way short of resources, and plenty of people lived there. These are all contemporary Bushman camps, with the same pottery found in the shelter.
By Spit 7 there is a first hint that their favorite southeastern quarries are falling out of use
… confirmed in Spit 6 and …
... completed through Spit 5, and....
… continuing up into Spit 4.
It appears that their foraging range was contracting to the west.

But could it be that we are looking at nothing more than sample-size attrition thro Spits 7-4?
This particular pottery decoration refutes the proposition that sample attrition caused that “shrinking to the west” pattern. Comb stamping seems to have been a very short-lived fashion. There’s one sherd like this in Spit 7, and another in Spit 5 out on the talus.
But comb-stamp is very common on camps in the west half of the study area, and still farther west it becomes the dominant pattern (and we have examined hundreds of sites).

On the east side of the study area its drops off sharply, which is why we get only two sherds of it in the shelter.

If their range was contracting westward at the time that comb-stamping came into fashion, this might explain its very restricted, westerly distribution.
So what have we learned? First of all, forget about pinpointing the source of a hornfels artifact. The best we can do is isolate an outcrop that’s a more likely candidate than its several rivals. We can only do this for about half the artifacts tested, and with varying degrees of confidence. Our not-very-rigorous test suggests we could be on the mark about 60% of the time. Of the rejects, PCA can confidently identify about 10% as non-local hornfels, the ones from outside our sampling circle.

But there are many more unmatched ones of uncertain origin, and we still don’t understand the meaning of those “ghosts” that join PCA clusters in spite of weak proximity values.
Overall, the usable fraction suggests that the shelter was a periodic stopover place for foragers locked into rotational mobility. The shelter appears to be on the SW rim of their foraging range, and they seldom if ever foraged upstream, probably because it was the territory of another band.

For reasons that remain unclear, their range contracted westward at a time when comb-stamp pottery decoration came into vogue, and its distribution mirrors that of the hornfels quarry use.

This is the most we can squeeze from the data.