# 74220

## Orange Soil

4567 grams

DRAFT

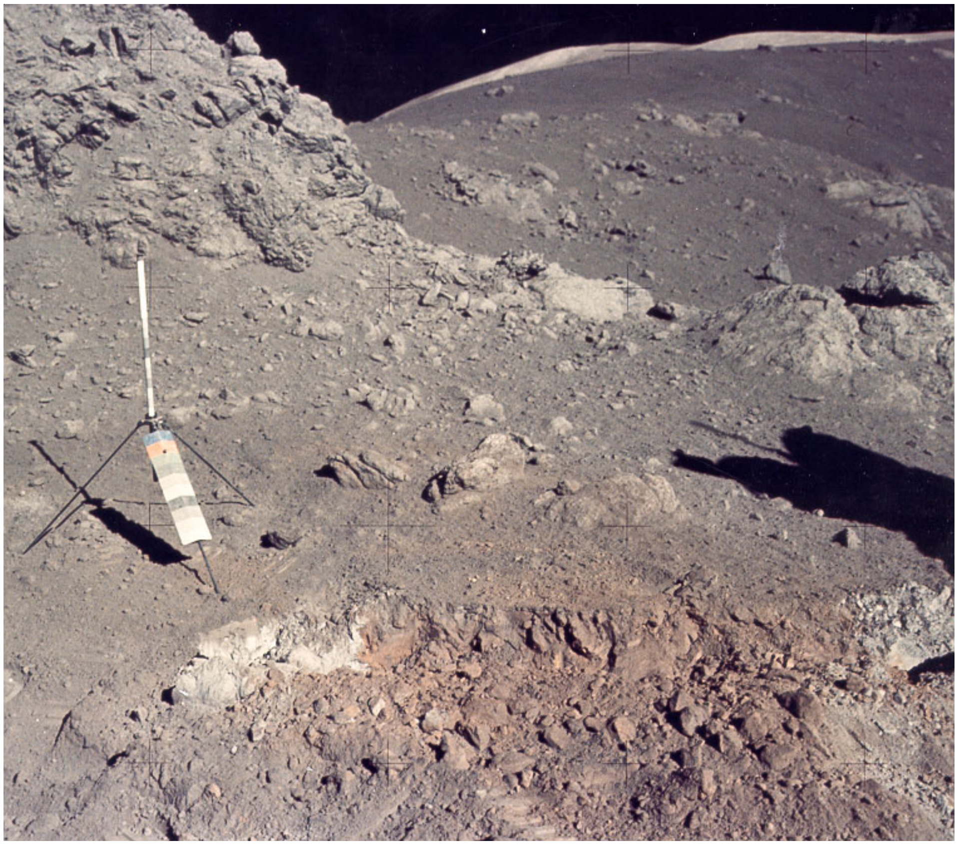

*Figure 1: Photo of trench dug into orange soil at rim of Shorty Crater, Apollo 17. NASA AS17-137-20990 (see map and sketch, figures 21, 22).*

### Introduction

The orange soil samples discovered at Shorty Crater, Apollo 17, consists of three samples of the trench pictured in figure 1 (74220, 74240 and 74260) and an adjacent double drive tube (74002-74001). 74220 and most of the drive tube are nearly pure orange glass, while 74240 and 74260 and the top 5 cm of the drive tube are mixtures of orange glass and local mare soil. A high portion of the orange glass in the drive tube is devitrified, and now black, due to fine olivine needles and ilmenite feathers. This is often referred to as "black glass", but compositionally, it is found to be the same as the orange glass.

**Orange Soil Samples**

| | Grams | Is/FeO | |
|---|---|---|---|
| 74220 | 1180 | 1 | surface sample |
| 74240-4 | 924 | 5.1 | trench sample |
| 74260-4 | 527 | 5 | trench sample |
| 74002 | 909.6 | 0.2 to 3 | drive tube, top |
| 74001 | 1072 | 0.2 | drive tube, bottom |
| total | 4567 | | |

The orange and black glass samples were identified as a pyroclastic deposit (Heiken et al. 1974, Meyer et al. 1975, Heiken and McKay 1977). Other origins (vapor condensation, impact) have been considered and rejected. Roedder and Weiblen (1973) considered an origin by meteorite impact into a lava lake, but this hypothesis has also been discounted.

Mafic volcanic glasses are found all over the moon (Delano 1986), but the Orange Soil (74220) and the Green Glass Clods (15425-7) are the "type samples"for pyroclastic deposits. The Orange Soil was found to be enriched volatile elements (Zn, Pb, S, Cl etc) and the glass beads were found to have a thin coating of condensed volatiles (Meyer et al 1975, Butler and

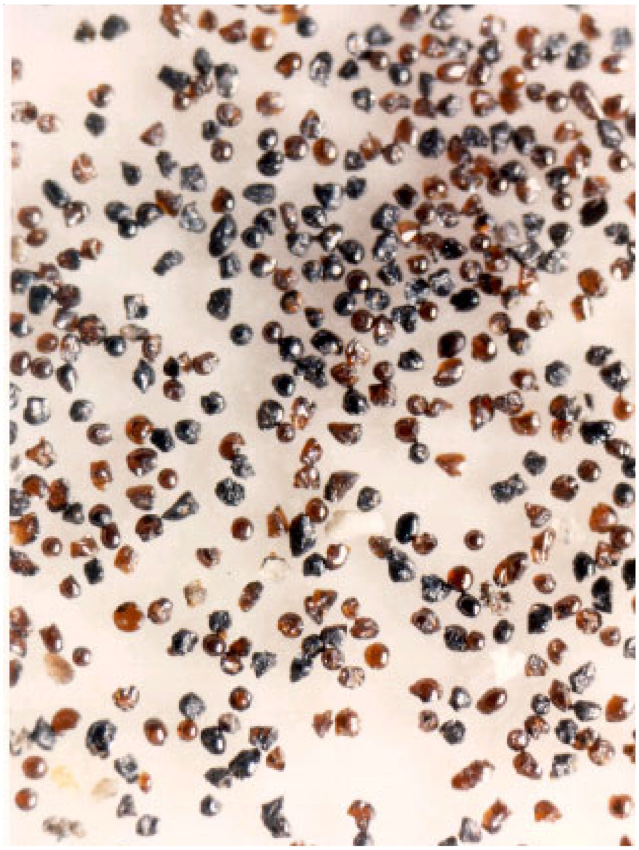

*Figure 2: Sieved and washed fraction of orange soil, 74220. Particle size is 100 microns. NASAS73-15085.*

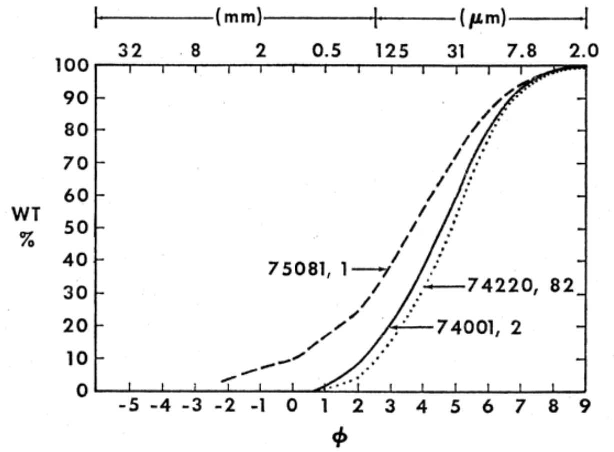


*Figure 3: Grain size distribution of orange soil (74220) and core tube (74001) compared with typical soil (75081) (from Heiken et al. 1974). Mean grain size of 74220 is 40 microns.*

Meyer 1976). The Orange Soil generally contains high levels of endogenous Ni (not due to meteorite contamination), as well as significant amounts of highly-siderophile-elements (Re, Os etc) that seem to be due to meteoritic contamination (Walker et al. 2004).

While the age of the orange glass is known to be about 3.6 b.y. (the same age as the mare basalts), the exact age of Shorty Crater has remained elusive (Eugster et al. 1981, Bogard and Hirsch 1978, Crozaz 1979). The cratering event that caused Shorty Crater would surely have modified these samples, as they were collected from the rim of the crater.

## Petrography

Although the orange soil is nearly pure orange glass, only about 1/3 of the sample is unbroken spheres and ovoids, while about 2/3 is made up of broken spheres and angular glass fragments (Heiken et al. 1974, Heiken and McKay 1974). None of the glass in this sample is similar to lunar agglutinates, nor contains broken mineral or lithic fragments characteristic of impact glass. The average grain size of 74220 is ~ 40 microns (figure 3). The orange soil samples (as measured by the Is/FeO parameter) are extremely immature (Morris 1978, Morris and Gose 1977). Thus, this soil is not like that of other lunar soils and is interpreted as a pyroclastic deposit (Heiken et al. 1974).

**Mineralogical Mode**

| | 74220 | 74220 | 74240 | 74260 | 74001 | 74002top | 74002 *(90-150 micron)* |
|---|---|---|---|---|---|---|---|
| *reference* | *Heiken and McKay 1974* | | | | | *McKay et al. 1978* | |
| Agglutinates | 1.3 % | 2.7 | 8 | 7.7 | | 13.2 | |
| Basalt | 1.6 | 2 | 30 | 23.7 | | 3.6 | |
| Breccia | 0.3 | 1.3 | 16.9 | 16.1 | | 1.4 | 0.1 |
| Anorthosite, Norite | | | 0.6 | | | | |
| Plagioclase | | 1 | 4.6 | 2.7 | 1.6 | 0.1 | |
| Pyroxene | 0.3 | 0.3 | 11.3 | 13.7 | 0.3 | 1.4 | |
| Olivine | | | | 0.3 | | | |
| Ilmenite | | 0.3 | 1.3 | 2.3 | | | |
| Glass | | | | | | | |
| Orange | 66.3 | 83.6 | 4 | 7.7 | 8 | | |
| Black | 29.3 | 6.7 | | 2 | 73.3 | 91.1 | 99.9 |
| Colorless | 0.3 | | 4.6 | 3.7 | | | |
| Brown | | 1.3 | 2.6 | 1.7 | 16.6 | | |
| Ropy | | 0.7 | 14.3 | 18.1 | | 0.1 | |
| Other | | | 0.3 | 0.3 | | 0.3 | |

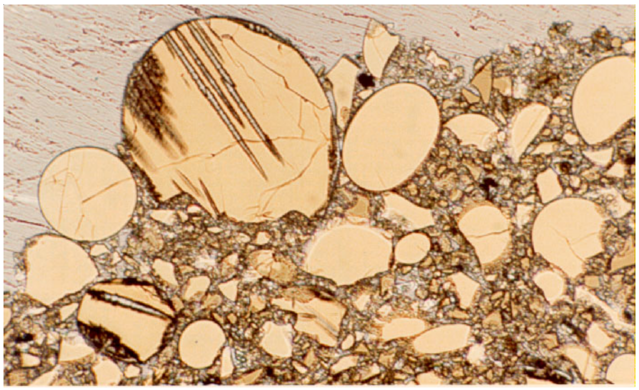

*Figure 4: Photomicrograph of thin section of 74220 illustrating orange glass beads and broken fragments. The orange glass partially crystallizes olivine needles with fine ilmenite margins. Large bead in this photo is ~ 1 mm. NASA#S79-27295.*

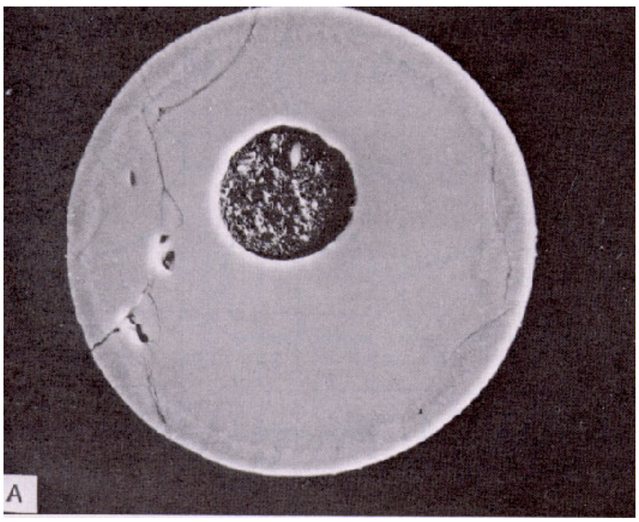


*Figure 5: Rare vesicle in glass sphere from 74001 (from Heiken and McKay 1978). Diameter of sphere is 140 microns.*

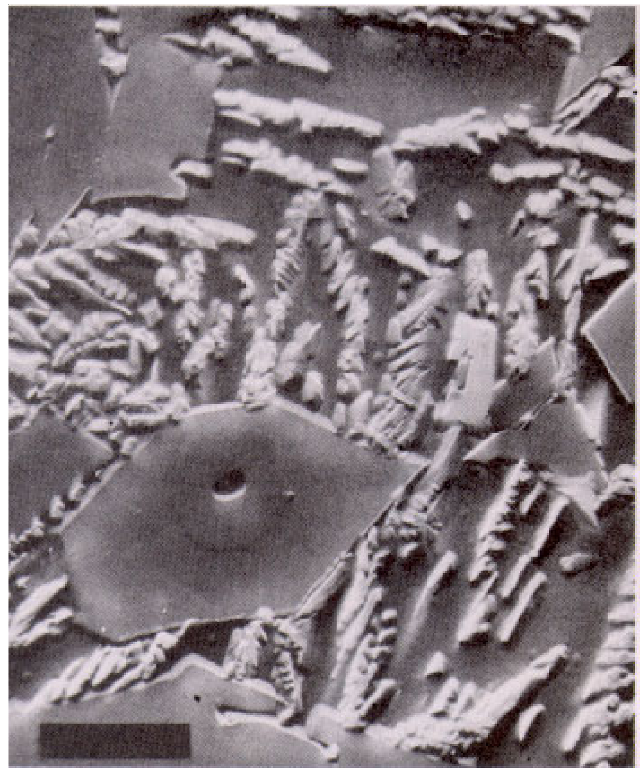

*Figure 6: Scanning-electron-microscope image of ion-etched thin section of "black glass" droplet from 74002 ilustrating minute olivine, ilmenite and chromite quench crystals in glass matrix. Ilmenite feathers are bright in this BSE image, but they cause the black appearence of glass beads. From Heiken and McKay (1977). Black scale bar is 10 microns.*

The orange soil is mostly orange glass beads and broken fragments of the same (figure 2). Heiken and McKay (1974) and McKay et al. (1978) determined the mineralogical mode and described the shape and crystallinity of the glass beads (see table). The petrography of the core (74002, 74001) is described in McKay et al. (1978). The core varies in its ratio of orange glass to devitrified black glass. Many beads are broken, presumably by the impact that made Shorty Crater. Few glass beads have vesicles (figure 5).

The devitrification features of the orange and black glass spheres in 74220 and 74001 are described by Haggerty (1974), Arndt and Engelhardt (1987) and Heiken and McKay (1978). Quench crystals of olivine and ilmenite (figures 4 and 6) make devitrified orange

**Shape and Crystallinity of Glass Droplets** (from Heiken et al. 1974, Heiken and McKay 1978)

| Sample # | depth | droplet shape | | | crystallinity | | |
|---|---|---|---|---|---|---|---|
| | | sphere | ovoid | compound | glass | partly | crystalline |
| 74002,179 | 5 cm | 47 % | 42 | 11 | 46 % | 30 | 24 |
| 74002,181 | 18 | 46 | 37 | 17 | 15 | 19 | 66 |
| 74001,98 | 32 | 70 | 26 | 4 | 4 | 11 | 86 |
| 74001,113 | 44 | 53 | 34 | 13 | 2 | 9 | 90 |
| 74001,125 | 57.5 | 35 | 23 | 41 | 2 | 5 | 93 |
| | | sphere | ovoid | broken fragments | | | |
| 74220,85A | | 20 % | 5 | 74 | | | |
| 74220,85B | | 30 | 11 | 58 | | | |
| 74220,85C | | 20 | 5 | 75 | | | |
| 74220,85D | | 32 | 2 | 66 | | | |

glass appear opaque (black). These black glass droplets are found to have the same chemical composition as the orange glass (Heiken and McKay 1974). Olivine composition is $Fo_{68-82}$ (Prinz et al. 1973, Taylor and Carter 1974 and Heiken et al. 1974).

The grey samples collected from the ends of the trench (74240 and 74260) also contain ropy glasses of presumed impact origin (Fruland et al. 1977, Korotev and Kremser 1992) as well as a variety of breccias and basalts.

The surfaces of the orange glass spheres are found to have a unique coating of micromounds (100 to 1000 ìm) (Heiken et al. 1974, Meyer et al. 1975, Clanton et al. 1978). In some places the coating has been scraped off (figure 7). The coatings were found to be made of mixed salts, with ZnS as a main component (figure 8). Very few micrometeorite craters were found on the surfaces of the spheres.

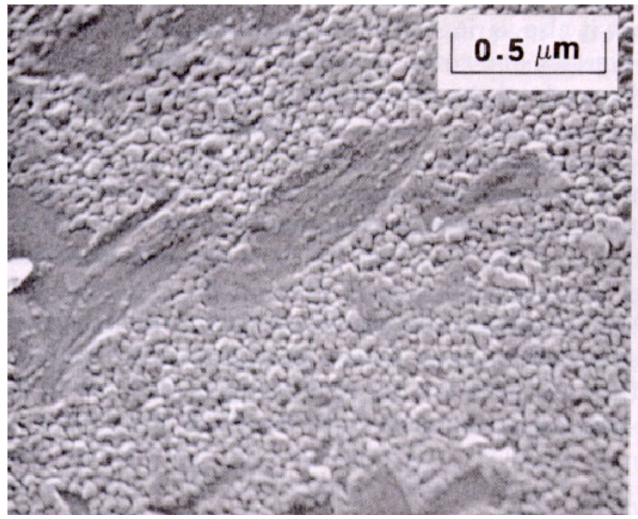


*Figure 7: ZnS rich coating on glass sphere from 74001 (from Clanton et al. 1978).*

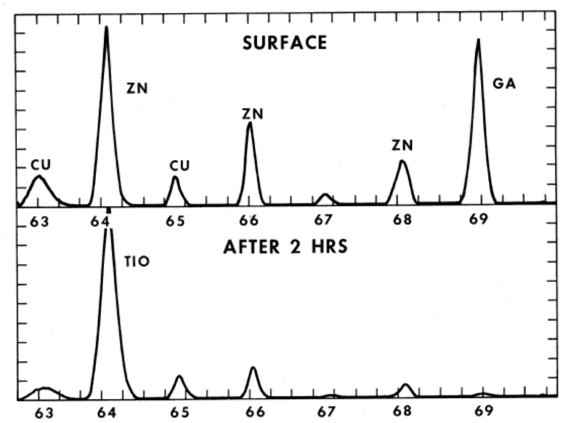


*Figure 8: Ion microprobe mass scans of surface and ion-etched surface of orange glass sphere from 74220 showing that Zn, Cu and Ga were present in the surface deposit, but etched away after 2 hrs. of ion bombardment (Meyer et al. 1975).*

## Surface-correlated volatiles

Tatsumoto et al. (1973) was the first to notice that the 74220 contained surface-correlated volatiles (Pb). Gibson and Moore (1973a,b) noted that 74220 was unusual as a lunar soil in that it gave off $SO_2$ at a low temperature (figure 13). By analyzing different size fractions, Thode and Rees (1976) showed that the sulfur was enriched on the surfaces of the grains, but they found that $^{34}S$ remained constant over different size fraction (unlike the case for all other lunar soils). Jovanovic et al. (1973) found that 74220 was enriched in Cl and Te and suggested that the source of high halogens was "fumarolic activity". Jovanovic and Reed (1974) and Wanke et al. (1973) found 74220 to be enriched in halogens (table 6) and Goldberg et al. (1976) showed the F to be a surface deposit (figure 9).

Meyer et al. (1975) and Wasson et al. (1976) hypothesized that halogens were in the vapor of the lava fountain, because of the increased volatility of various metals as chlorides and because some Cl and F was found on the surface of the glass. Cirlin and Housley (1977) used a technique that involved HF treatment to enhance thermal release of Pb, to show that the Pb was indeed present as $PbCl_2$ on the surface of the orange glass. Bell et al. (1974) reported evidence of $FeCl_2$.

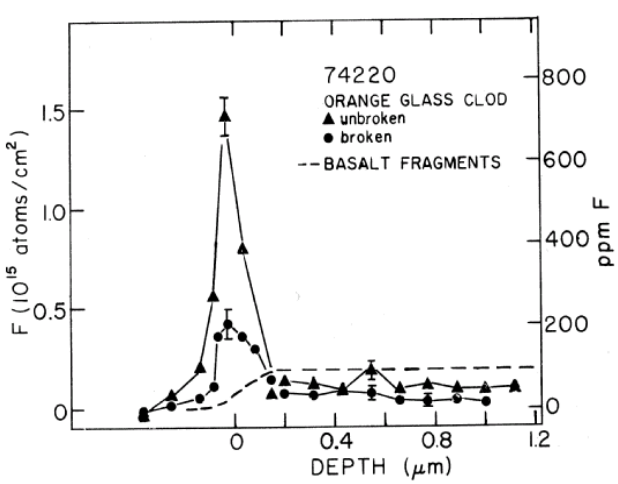


*Figure 9: Flourine depth profile for samples of 74220 (from Goldberg et al. 1976)*

Reed et al. (1977) and others have carefully studied the behavior of Zn, Pb and other elements during various kinds of leaching and conclude that although

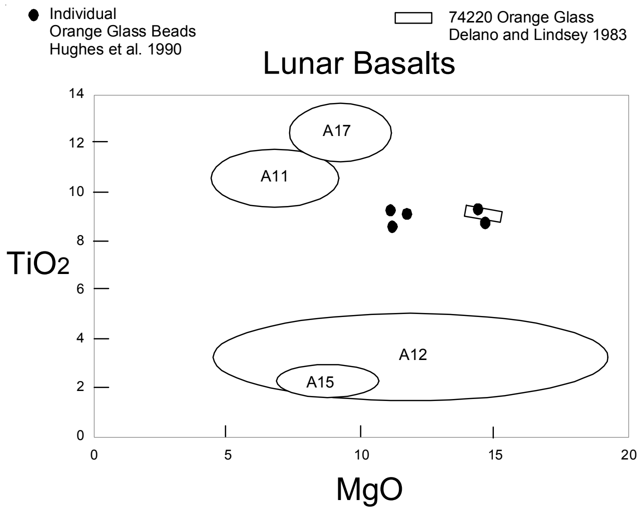


*Figure 10: Orange glass compositions from 74220 (data from Reid et al. 1973, Delano and Lindsey 1983). Analyses of individual orange glass beads from other orange soil samples are variable (data from Hughes et al. 1990).*

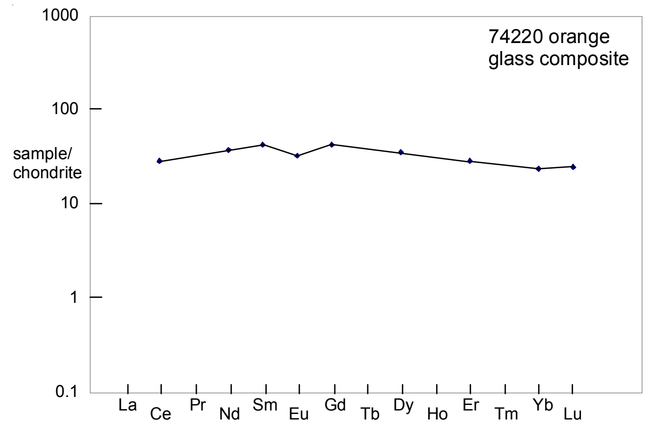


*Figure 11: Normalized rare-earth-element pattern for composite of orange glass spheres from 74220 (data from Philpotts et al. 1974).*

these elements are present in surface coating, they are not easily released. Krahenbuhl (1980) showed convincingly that Zn, Hg, Ge, Au and Ir were on the surfaces of the particles by carefully analyzing different grain sizes of the core tube 74002/1. Eugster et al. (1981) also showed that Br, and I were "anti-correlated" with grain size and thus on the surfaces of the glass beads. Meyer et al. (1975) used the ion microprobe to show that Zn, Cu, Ga, Pb and other elements were on the surfaces of glass beads from 74220. (figure 8). Butler and Meyer (1976) showed that the prevalent coating material (micromounds) contained sulfur. Nearly everyone agrees that the volatile element deposit on the glass beads was due to condensation of gas from volcanic eruption (figure 12).

## Double Drive Tube 74002 – 74001

A 67 cm long double drive tube was collected from close to the trench at Shorty Crater. Nagel (1978), McKay et al. (1978), Morris et al. (1978), Bogard and Hirsch (1978), Blanchard and Budahn (1978), Crozaz (1978) and Heiken and McKay (1978) studied the double drive tube. Eugster et al. (1979, 1980, 1981) determined the age and exposure history of this important sample. Clanton et al. (1978) and Cirlin et al. (1979) studied the surface coatings on the particles.

## Chemistry

There are at least three important, variable, chemical components to consider in understanding the orange soil (endogenous volcanic melt, volcanic exhalation, and meteoritic contamination). The volcanic exhalation is seemingly coupled to the endogenous component in time (Tera and Wasserburg 1976). Morgan and Wandless (1979) used volatile and siderophile element data from the core tube to unravel the contributions from meteorites and volcanic exhalations. Recently, Walker et al. (2004) have shown that the highly-siderophile-elements (namely Os) are greatly depleted in the orange glass.

Table 1 and figure 11 give the chemical composition of the bulk samples. Portions of the orange soil (74220) and the core (74002/1) are relatively uncontaminated by lunar regolith, and closely match the composition of the glass beads. However, in the bulk trench samples (74240 and 74260) and the top 5 cm of the core (74002), there is also a variable amount of mixing (by gardening) with lunar regolith.

Numerous investigators analyzed a large number of orange and black glass beads from Apollo 17 (table 5). Delano and Lindsey (1983) and Delano (1986) have identified several (~25) groups of volcanic glass, but found that the orange glass from 74220 was very constant in composition (figure 10). Hughes et al. (1990) analyzed some of the individual glass particles for a long list of elements (table 2).

Delano (1986) found that mafic volcanic glasses always have relatively high Ni, so Ni, at least, is not an indicator of meteoritic contamination in these samples.

The special feature of the orange glass samples is that they are found to be enriched in Zn, Cu, Ag, Cd, Tl, Br (and other metal halides) when compared to other lunar

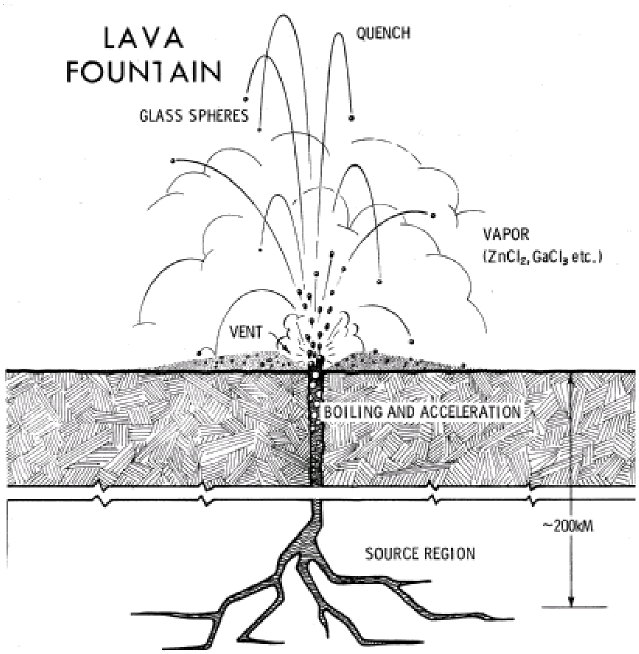


*Figure 12: Sketch of hypothetical lava fountain that could have produced the features seen in the volcanic glass beads in 74220 (from Meyer et al. 1975).*

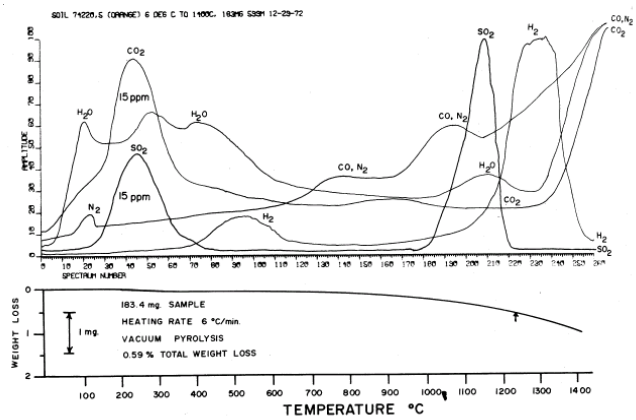


*Figure 13: Gas release profile of 74220 showing low temperature release of carbon and sulfur species (from Gibson and Moore 1973).*

samples (Morgan et al. 1974, Duncan et al. 1974) and this has been much discussed (see section of surface-correlated volatiles). Table 6 tabulates some of the analytical results for halogens and sulfur in the orange glass samples. While sulfur is not high in the bulk sample, it is an important component in the surface deposits (see Butler and Meyer 1976).

Various investigators (Walker et al. 2004, Krahenbuhl 1980, Wasson et al. 1976) have etched or leached the surfaces of the glass beads in an effort to separate the components (figure 14).

## Radiogenic age dating

Husain and Schaeffer (1973), Huneke et al. (1973), Eberhardt et al. (1975), Alexander et al. (1978) and Huneke (1978) determined the age of the orange glass spheres by $^{39}Ar$-$^{40}Ar$ plateau (figures 15, 16 and table). In a "tour-de-force", Huneke dated individual glass beads at about 3.6 b.y. (figure 18). Tera and Wasserburg (1976) used the lead isotopes leached from the surface, along with the residue, to date the age of formation of the orange soil (figure 17). U, Th and Pd data for 74220, 74240, 74260 and 74001 are also given in Nunes et al. (1974), Silver (1974) and Tatsumoto et al. (1987). They note that $^{204}Pb$ is relatively high and easily released by mild thermal heating, or leaching.

## Cosmogenic isotopes and exposure ages

Keith et al. (1974), Fruchter et al. (1978) and Murrell et al. (1979) determined the radioactivity of 74220 and 74002/1, due to cosmic ray interaction (table 4). Based on $^{22}Na$, $^{26}Al$ activity, Fruchter et al. (1978) found that the top 2-3 cm of the core has been actively mixed with mare components (gardened) and about 2 cm of soil might be missing from the top of the core. Murrell et al. (1979) found the top of the core was undersaturated in $^{53}Mn$.

Kirsten et al. (1973), Fleischer and Hart (1974), Hutcheon et al. (1974) and Crozaz (1978) reported nuclear track ages for orange soil samples (~ 10 m.y.).

Kirsten et al. (1973), Schaeffer and Husain (1973) and Hintenberger et al. (1974) reported the exposure age of 74220 as 30 m.y., 32 m.y. and 27 m.y., respectively. However, Bogard and Hirsch (1978) found that the data for the nearby core required a two-stage cosmic-ray exposure – 20 m.y. initially, followed by 10 m.y. (the presumed age of Shorty Crater). Eugster et al. (1977 and 1981) offer a different irradiation model based on an age of ~17 m.y. for Shorty Crater. The sample may have also been irradiated for up to 35 m.y., right after it erupted !

Another interesting discovery was that the Apollo 17 orange soil sample is unique among all lunar soils, in that it shows no surface $^{18}O$, $^{30}Si$ or $^{34}S$ enrichment, which means it could not have been exposed to the lunar surface for any length of time (Taylor and Epstein 1974, Thode and Rees 1976).

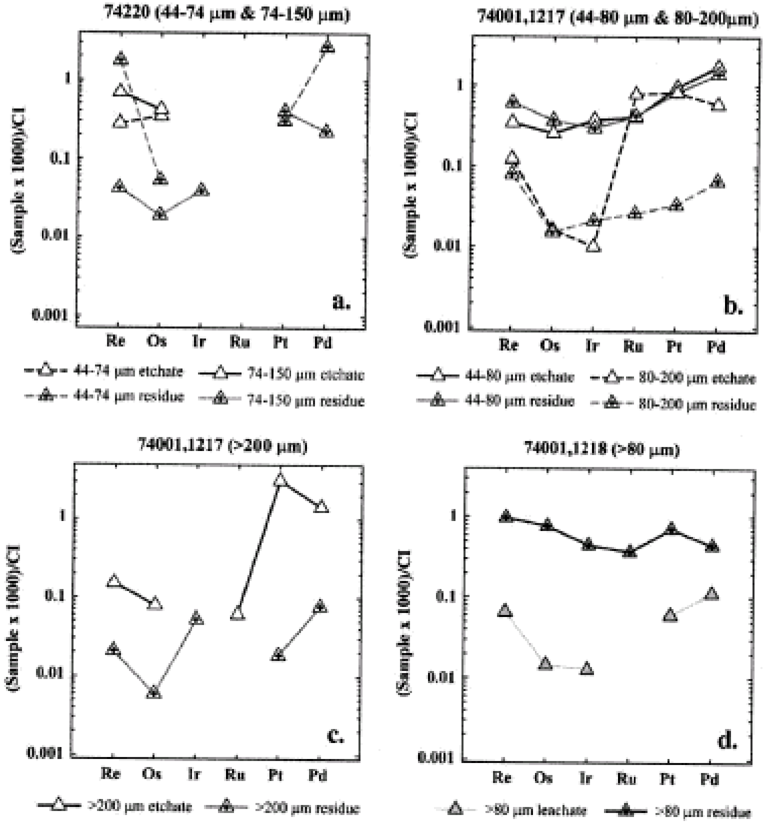


*Figure 14: Concentration of highly-siderophile-element (HSE) elements in etchates and residue of hand-picked orange glass spheres (large and small), from 74220 and 74001 (core). Data and figure from Walker et al. (2004). See table 3.*

## Processing

The location of the trench and core tube on the rim of Shorty Crater are discussed in Muehlberger et al. (1973) and Wolf et al. (1981) (figure 20 and 21) and the samples were described in Apollo 17 PET (1973).

Only a portion of 74220 was sieved. In the sieving that was done, there were some orange glass clods that were found, but these remain unstudied. There also remain unsieved portions of 74240 and 74260 (figure 22).

Various investigators (e.g. Krahenbuhl 1980) sieved the samples to obtain results on different size fractions.

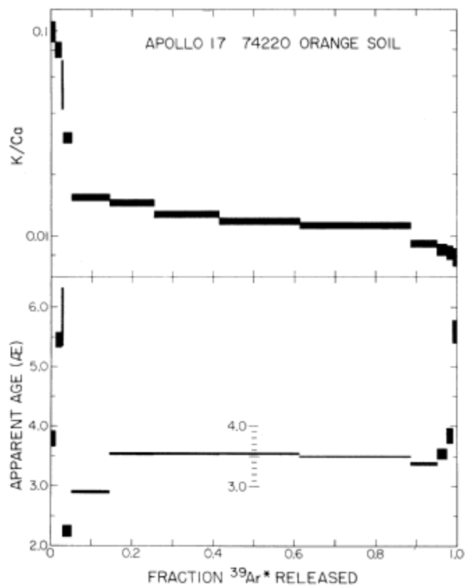


*Figure 15: Argon release diagram for composite of orange glass spheres from 74220 (from Huneke et al. 1973).*

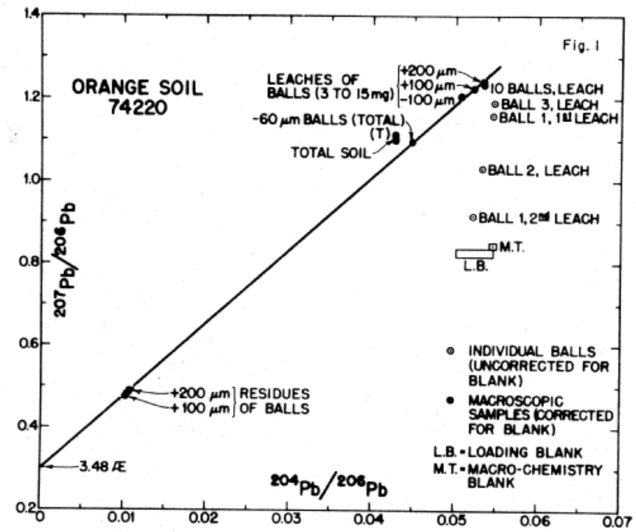


*Figure 17: Pb/Pb diagram for orange glass spheres and composites from 74220 (from Tera and Wasserburg 1976).*

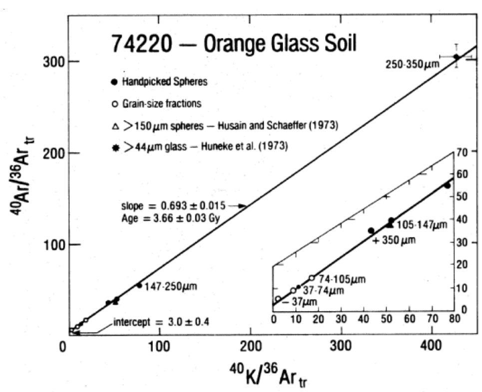


*Figure 16: K/Ar data for orange glass from 74220 (from Alexander et al. 1978).*

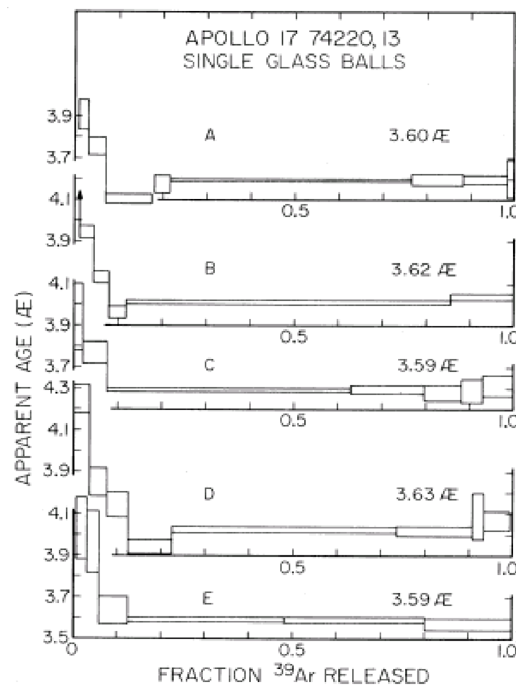


*Figure 18: Argon release patterns for individual orange glass beads from 74220 (from Huneke 1978).*

## Summary of Age Data for 74220 and 74001

| | Ar/Ar | Pb/Pb | 74001 Ar/Ar |
|---|---|---|---|
| Husain and Schaeffer 1973 | 3.71 ± 0.06 b.y. | | |
| Eberhardt et al. 1973 | 3.67 ± 0.04 | | |
| Eberhardt et al. 1975 | | | 3.66 |
| Huneke et al. 1973 | 3.54 ± 0.05 | | |
| Huneke 1978 | 3.60 ± 0.04 | | |
| Alexander et al. 1978 | 3.66 ± 0.03 | | |
| Saito and Alenxander 1979 | | | 3.7 |
| Tatsumoto et al. 1973 | | 3.63 | |
| Tera and Wasserburg 1976 | | 3.48 ± 0.03 | |
| Hutcheon et al. 1974 | ~3.7 (fission track age) | | |

**Note: Beware decay constant.**

## Other Measurements for Orange Soil

Viscosity and heat capacity
- Uhlmann et al. (1973)

Magnetics
- Brecher A. and Morash K.R. (1973)
- Brecher et al. (1974)
- Olhoeft G.R. and Stangway D.W. (1973)
- Stone et al. (1982)

Isotopes
- Epstein S. and Taylor H.P. (1973)
- Taylor H.P. and Epstein S. (1973)
- Thode H.G. and Rees C.E. (1976)
- Silver (1974)
- Tatsumoto et al. (1973, 1978)
- Tera and Wasserburg (1976)

Rare Gasses
- Eberhardt et al. (1975)
- Eugster et al. (1977, 1979, 1980, 1981)
- Bogard and Hirsch (1978)
- Hintenberger et al. (1974)
- Kirsten et al. (1973)

Gas release
- Epstein S. and Taylor H.P. (1973)
- Gibson E.K. and Moore G. (1973)
- Gibson E.K. and Moore G. (1974)
- Jovanovic S., Jensen K. and Reed G.W. (1973)

Nuclear Tracks
- Crozaz (1978, 1979)
- Kirsten et al. (1973)
- Fleischer and Hart (1974)
- Hutcheon et al. (1974)

Experimental Petrology
- Green et al. (1975)
- Sato (1979)

Adsorption Isotherms
- Cadenhead and Stetter (1974)
- Cadenhead and Buerget (1974)

Depth Profile
- Murrell et al. (1979)
- Fruchter et al. (1978)

Surface features
- Carter et al. (1973)
- Holmes et al. (1974)
- Butler (1978)
- Grant et al. (1974)

Spectra
- Pieters et al. (1980)
- Mao et al. (1973)
- Vaughan and Burns (1973)

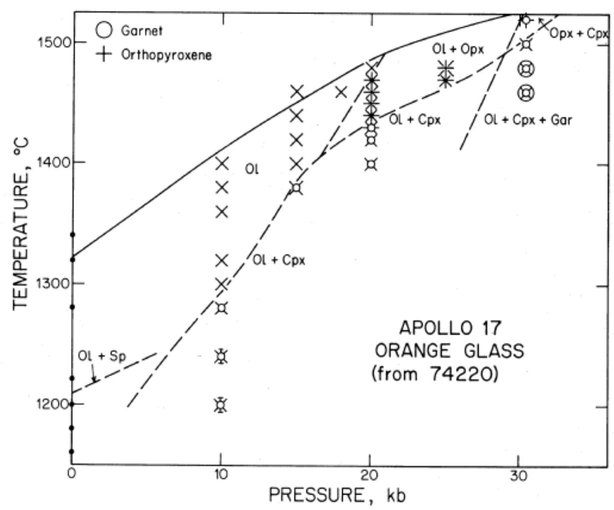


*Figure 19: Experimental crystallization of 74220 orange glass at high pressure (from Green et al. 1975).*


*Figure 20: Clods of orange soil, sample number 74220,8. Scale in mm. NASA photo# S75-34259.*

## Table 1a. Chemical composition of Shorty Trench.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | core ave. |
| *reference* | Kieth 74 | Rhodes 74 | Wiesmann | Rhodes | Rhodes | Wiesmann | Rhodes | Nava 74 | Nava 74 | Rose 74 | Rose 74 | Blanchard 78 |
| *weight* | *74220* | 74220 (b) | 74220 (a) | 74240 | 74241 | 74241 (a) | 74260 | 74220 | 74241 | 74241 | 74261 | 74001/2 |
| SiO2 % | | 38.57 | | 40.78 | 41.55 | | 41.22 | 38.9 | 42.3 | 42 | 42.08 | |
| TiO2 | | 8.81 | 8.5 | 8.61 | 7.45 | | 7.68 | 8.96 | 7.33 | 7.9 | 7.45 | 8.9 |
| Al2O3 | | 6.32 | | 12.54 | 13.35 | | 13.25 | 6.38 | 13.69 | 13.19 | 13.7 | 5.8 |
| FeO | | 22.04 | | 15.84 | 14.89 | | 15.31 | 22.34 | 14.66 | 14.84 | 14.96 | 23.7 |
| MnO | | 0.3 | | 0.24 | 0.22 | | 0.23 | 0.255 | 0.202 | 0.2 | 0.19 | 0.27 |
| MgO | | 14.44 | | 9.15 | 9.19 | | 9.47 | 14.76 | 9.88 | 9.17 | 9.56 | 15 |
| CaO | | 7.68 | | 11.36 | 11.54 | | 11.37 | 7.01 | 10.89 | 11.56 | 11.25 | 7.6 |
| Na2O | | 0.36 | | 0.38 | 0.48 | | 0.38 | 0.43 | 0.48 | 0.43 | 0.42 | 0.42 |
| K2O | 0.082 | 0.09 | 0.084 | 0.12 | 0.12 | 0.12 | 0.12 | 0.076 | 0.123 | 0.14 | 0.13 | |
| P2O5 | | 0.04 | | 0.09 | 0.1 | | 0.09 | 0.097 | 0.124 | 0.1 | 0.09 | |
| S % | | 0.07 | | 0.14 | 0.12 | | 0.12 | | | | | |
| *sum* | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| Sc ppm | | | | | | | | | | 59 | 57 | 48 |
| V | | | | | | | | | | 75 | 70 | |
| Cr | | | 4650 | | | 2676 | | | | 2874 | 3284 | 5200 |
| Co | | | | | | | | | | 28 | 38 | 66 |
| Ni | | 83 | | 80 | 101 | | 99 | | | 126 | 133 | |
| Cu | | | | | | | | | | 28 | 32 | |
| Zn | | 292 | | 96 | 96 | | 109 | | | 37 | 35 | |
| Ga | | | | | | | | | | 10 | 10 | |
| Ge ppb | | | | | | | | | | | | |
| As | | | | | | | | | | | | |
| Se | | | | | | | | | | | | |
| Rb | | 1.2 | 1.107 | 2.3 | 2.5 | 2.423 | 2 | | | 1.8 | 2 | |
| Sr | | 205 | 209 | 163 | 154 | 159 | 167 | | | 144 | 151 | |
| Y | | 49 | | 80 | 74 | | 75 | | | 90 | 74 | |
| Zr | | 182 | 185 | 235 | 232 | 218 | 239 | | | 352 | 286 | |
| Nb | | 15 | | 19 | 19 | | 19 | | | 14 | 23 | |
| Mo | | | | | | | | | | | | |
| Ru | | | | | | | | | | | | |
| Rh | | | | | | | | | | | | |
| Pd ppb | | | | | | | | | | | | |
| Ag ppb | | | | | | | | | | | | |
| Cd ppb | | | | | | | | | | | | |
| In ppb | | | | | | | | | | | | |
| Sn ppb | | | | | | | | | | | | |
| Sb ppb | | | | | | | | | | | | |
| Te ppb | | | | | | | | | | | | |
| Cs ppm | | | | | | | | | | | | |
| Ba | | | 76.4 | | | 112 | | | | 84 | 140 | |
| La | | | 6.25 | | | 9.95 | | | | | | 5.9 |
| Ce | | | 19 | | | 28.8 | | | | | | 21 |
| Pr | | | | | | | | | | | | |
| Nd | | | 17.8 | | | 24 | | | | | | |
| Sm | | | 6.53 | | | 8.55 | | | | | | 6.9 |
| Eu | | | 1.8 | | | 1.6 | | | | | | 1.88 |
| Gd | | | 8.52 | | | 12.6 | | | | | | |
| Tb | | | | | | | | | | | | 1.6 |
| Dy | | | 9.4 | | | 13.7 | | | | | | |
| Ho | | | | | | | | | | | | |
| Er | | | 5.1 | | | 8.07 | | | | | | |
| Tm | | | | | | | | | | | | |
| Yb | | | 4.43 | | | 7.45 | | | | 10 | 7.2 | 4.2 |
| Lu | | | 0.611 | | | | | | | | | 0.59 |
| Hf | | | | | | | | | | | | 6.3 |
| Ta | | | | | | | | | | | | 1.2 |
| W ppb | | | | | | | | | | | | |
| Re ppb | | | | | | | | | | | | |
| Os ppb | | | | | | | | | | | | |
| Ir ppb | | | | | | | | | | | | |
| Pt ppb | | | | | | | | | | | | |
| Au ppb | | | | | | | | | | | | |
| Th ppm | 0.65 | | | | | 1.32 | | | | | | 0.4 |
| U ppm | 0.164 | | 0.16 | | | 0.37 | | | | | | |
| *technique* | *(a) IDMS, (b) XRF, (c ) INAA* | | | | | | | | | | | |

## Table 1b. Chemical composition of Shorty Trench.

| | | spheres | | | | | | bulk | 500-62 micron | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *reference* | Philpotts 74 (a) | | | Korotev 92 | | | | Wasson 76 | | | | | | Wanke 73 | |
| *weight* | 74220 | 74220S | 74241 | 74220 | 74241A | 74241B | 74261 | 74220 | leach | etch | residue | total | | 74220 | 74241 |
| SiO2 % | | | | 38.3 | 40.8 | 41.3 | 41.3 | | | | | | (c ) | 39.36 | 42.36 |
| TiO2 | | | | 8.8 | 8.7 | 7.6 | 7.5 | | | | | | (c ) | 8.09 | 6.49 |
| Al2O3 | | | | 6.8 | 12.9 | 13.8 | 13 | | | | | | (c ) | 6.52 | 13.9 |
| FeO | | | | 22.4 | 16.2 | 15.4 | 15.8 | 23.8 | 0.68 | 2.56 | 20.97 | 24.19 | (c ) | 21.87 | 15.18 |
| MnO | | | | | | | | 0.275 | 0.01 | 0.03 | 0.23 | 0.272 | (c ) | 0.25 | 0.19 |
| MgO | | | | 14.28 | 8.8 | 9.02 | 9.68 | | | | | | (c ) | 14 | 9.27 |
| CaO | | | | 7.8 | 11.1 | 11.4 | 11.1 | 6.16 | 0.18 | 0.01 | 6.16 | 6.43 | (c ) | 7.4 | 11.4 |
| Na2O | 0.078 | 0.064 | 0.124 | 0.366 | 0.457 | 0.471 | 0.476 | 0.274 | 0.01 | 0.03 | 0.206 | 0.247 | (c ) | 0.4 | 0.45 |
| K2O | | | | | | | | | | | | | | 0.076 | 0.1 |
| P2O5 | | | | | | | | | | | | | | 0.048 | 0.1 |
| S % | | | | | | | | | | | | | | | |
| *sum* | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Sc ppm | | | | 48.3 | 61 | 57.3 | 53.9 | 37 | 1 | 0.18 | 35 | 36 | (c ) | 42.5 | 50.2 |
| V | | | | | | | | | | | | | | 130 | |
| Cr | | | | 4650 | 2780 | 2800 | 2950 | 5030 | 136 | 456 | 4460 | 5050 | (c ) | 4030 | 2320 |
| Co | | | | 61.5 | 26.3 | 26.7 | 30.2 | 68 | 2.4 | 6.7 | 60 | 69 | (c ) | 55.5 | 24.5 |
| Ni | | | | 113 | 90 | 140 | 120 | 110 | 3.6 | 8.9 | 71 | 83 | (c ) | 67 | 82 |
| Cu | | | | | | | | | | | | | | 25 | 21 |
| Zn | | | | | | | | 194 | 43 | 5.3 | 17 | 65 | (b) | 270 | 88 |
| Ga | | | | | | | | 16.1 | 2.9 | 0.79 | 2.5 | 6.2 | (b) | 16.5 | 13.4 |
| Ge ppb | | | | | | | | 401 | 80 | 20 | 143 | 243 | (b) | 260 | 210 |
| As | | | | | | | | | | | | | | 15 | 22 |
| Se | | | | | | | | | | | | | | | |
| Rb | 1.11 | 0.644 | 2.55 | | | | | | | | | | | 1.86 | |
| Sr | 206 | 205 | 155 | 235 | 170 | 210 | 140 | | | | | | | 160 | 140 |
| Y | | | | | | | | | | | | | | 44 | 61 |
| Zr | 184 | 194 | 565 | 175 | 270 | 200 | 250 | | | | | | | 162 | 204 |
| Nb | | | | | | | | | | | | | | 13 | 15.1 |
| Mo | | | | | | | | | | | | | | | |
| Ru | | | | | | | | | | | | | | | |
| Rh | | | | | | | | | | | | | | | |
| Pd ppb | | | | | | | | | | | | | | | |
| Ag ppb | | | | | | | | | | | | | | | |
| Cd ppb | | | | | | | | 314 | 122 | 7.2 | 28 | 157 | (b) | | |
| In ppb | | | | | | | | 29 | 6.6 | 0.41 | 0.71 | 7.7 | (b) | | |
| Sn ppb | | | | | | | | | | | | | | | |
| Sb ppb | | | | | | | | | | | | | | | |
| Te ppb | | | | | | | | | | | | | | | |
| Cs ppm | | | | | | | | | | | | | | 0.078 | |
| Ba | 78.4 | 73.9 | 116 | 78 | 120 | 109 | 127 | | | | | | (c ) | 130 | 120 |
| La | | | | 5.94 | 9.72 | 9.93 | 9.37 | 5.4 | 0.35 | 0.06 | 5.2 | 5.6 | (c ) | 6.5 | 10.9 |
| Ce | 19.9 | 17.7 | 29.6 | 18.1 | 29 | 29.5 | 27 | 19 | 0.9 | 0.2 | 19 | 20 | (c ) | 18 | 34 |
| Pr | | | | | | | | | | | | | | 2.5 | 4.4 |
| Nd | 17.9 | 17.4 | 24.8 | 17 | 22 | 24 | 17 | | | | | | | 16 | 31 |
| Sm | 6.5 | 6.4 | 8.8 | 6.71 | 9.05 | 8.72 | 8.21 | 5.2 | 0.29 | 0.06 | 5.3 | 5.6 | (c ) | 6.7 | 8.7 |
| Eu | 1.84 | 1.83 | 1.64 | 1.79 | 1.68 | 1.55 | 1.63 | 1.7 | 0.05 | 0.02 | 1.6 | 1.67 | (c ) | 1.83 | 1.65 |
| Gd | 8.46 | 8.5 | 12.2 | | | | | | | | | | (c ) | 9.3 | 11.1 |
| Tb | | | | 1.48 | 2.19 | 2.1 | 1.91 | | | | | | (c ) | 1.6 | 1.9 |
| Dy | 9.16 | 8.82 | 14 | | | | | | | | | | | 9.5 | 14 |
| Ho | | | | | | | | | | | | | | 1.9 | 2.8 |
| Er | 4.82 | 4.59 | 7.85 | | | | | | | | | | | 5.4 | |
| Tm | | | | | | | | | | | | | | | |
| Yb | 4.2 | 3.96 | 7.6 | 4.31 | 7.78 | 7.52 | 6.95 | 4.1 | 0.16 | 0.05 | 3.7 | 3.9 | (c ) | 4.24 | 7.3 |
| Lu | 0.627 | 0.608 | 1.14 | 0.59 | 1.12 | 1.09 | 0.96 | 0.5 | 0.02 | 0.01 | 0.51 | 0.54 | (c ) | 0.58 | 1 |
| Hf | | | | 5.79 | 7.59 | 7.21 | 6.98 | 5.4 | 0.16 | 0.65 | 5 | 5.8 | (c ) | 5.3 | 6.4 |
| Ta | | | | 1 | 1.26 | 1.19 | 1.18 | 0.9 | 0.02 | 0.11 | 0.75 | 0.88 | (c ) | 1.1 | 1.3 |
| W ppb | | | | | | | | | | | | | | 83 | 200 |
| Re ppb | | | | | | | | | | | | | | | 0.2 |
| Os ppb | | | | | | | | | | | | | | | |
| Ir ppb | | | | <6 | 3.5 | 4 | 4.5 | 0.35 | 0.03 | 0.04 | 0.19 | 0.06 | (b) | | 7.9 |
| Pt ppb | | | | | | | | | | | | | | | |
| Au ppb | | | | <4 | 3.5 | 4 | <6 | 1.01 | 0.08 | 0.02 | 0.244 | 0.34 | (b) | 1.5 | 2.6 |
| Th ppm | | | | 0.42 | 0.99 | 1.24 | 1.1 | 0.61 | 0.02 | 0.09 | 0.58 | 0.7 | (c ) | | |
| U ppm | | | | 0.13 | 0.4 | 0.26 | 0.23 | | | | | | (c ) | 0.15 | 0.37 |
| *technique* | *(a) IDMS, (b) RNAA, (c ) INAA* | | | | | | | | | | | | | | |

## Table 1c. Chemical composition of Shorty Trench (cont.).

| | | bulk | spheres | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *reference* | Duncan 74 | Morgan 74 | | | | | Morgan 79 | | | Krahenbuhl 80 | | | | Miller 74 |
| *weight* | 74220 | 74220 | dark | orange | 74001 | 74241 | 74001 | 74001 | 74001 | 74002 | 74002 | 74001 | 74001 | 74220 |
| SiO2 % | 39.03 | | | | | | | | | | | | | 39.58 |
| TiO2 | 8.72 | | | | | | | | | 7.45 | 7.66 | 7.52 | 7.52 | 10 |
| Al2O3 | 6.47 | | | | | | | | | | | | | 6.6 |
| FeO | 22.13 | | | | | | | | | | | | | 21.23 |
| MnO | 0.273 | | | | | | | | | | | | | 0.27 |
| MgO | 14.44 | | | | | | | | | | | | | 15.1 |
| CaO | 7.62 | | | | | | | | | | | | | 9.23 |
| Na2O | 0.34 | | | | | | | | | | | | | 0.47 |
| K2O | 0.077 | | | | | | | | | | | | | |
| P2O5 | 0.043 | | | | | | | | | | | | | |
| S % | 0.073 | | | | | | | | | | | | | |
| *sum* | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| Sc ppm | | | | | | | | | | 47.9 | 47 | 47.6 | 45.7 | 46.9 |
| V | 132 | | | | | | | | | | | | | |
| Cr | 4680 | | | | | | | | | | | | | 3790 |
| Co | 62 | | | | | | | | | 62.8 | 63.6 | 62.3 | 60.3 | 63 |
| Ni | 74.7 | 67 | 70 | 72 | 68 | 64 | 66 | 51 | 53 | | | | | |
| Cu | 26.3 | | | | | | | | | | | | | |
| Zn | 253 | 230 | 45 | 141 | 148 | 86 | 178 | 185 | 151 | 196 | 103 | 140 | 134 | |
| Ga | | | | | | | | | | | | | | |
| Ge ppb | | 250 | 41 | 191 | 105 | 155 | 144 | 179 | 122 | 193 | 170 | 170 | 119 | |
| As | | | | | | | | | | | | | | |
| Se | | 640 | 129 | 460 | 350 | 340 | 380 | 490 | 353 | | | | | |
| Rb | 1.5 | 0.95 | 0.66 | 0.77 | 0.76 | 2.3 | | | | | | | | |
| Sr | 200 | | | | | | | | | | | | | |
| Y | 43.8 | | | | | | | | | | | | | |
| Zr | 186 | | | | | | | | | | | | | |
| Nb | 13.6 | | | | | | | | | | | | | |
| Mo | | | | | | | | | | | | | | |
| Ru | | | | | | | | | | | | | | |
| Rh | | | | | | | | | | | | | | |
| Pd ppb | | | | | | | 1.1 | 1.3 | 1.7 | | | | | |
| Ag ppb | | 111 | 320 | 75 | 72 | 25 | 82 | 116 | 75 | | | | | |
| Cd ppb | | 320 | 92 | 260 | 25 | 210 | 59 | 18 | 9 | 178 | 35.5 | 45.9 | 11.4 | |
| In ppb | | 29 | | | | | 10 | 14 | 6.3 | 35.4 | 19.3 | 10 | 8.3 | |
| Sn ppb | | | | | | | | | | | | | | |
| Sb ppb | | 0.65 | 1 | 25 | 1.16 | 0.55 | 1.25 | 0.73 | 0.77 | | | | | |
| Te ppb | | 62 | 10 | 49 | 38 | 24 | | | | 79.3 | 50.8 | 105 | 61.9 | |
| Cs ppm | | 0.053 | 0.03 | 0.045 | 0.037 | 0.107 | | | | | | | | |
| Ba | 82 | | | | | | | | | | | | | |
| La | | | | | | | | | | 6.11 | 5.85 | 6 | 5.64 | 7 |
| Ce | | | | | | | | | | 29 | 26.7 | 31.4 | 26.6 | |
| Pr | | | | | | | | | | | | | | |
| Nd | | | | | | | | | | | | | | |
| Sm | | | | | | | | | | | | | | |
| Eu | | | | | | | | | | | | | | 1.9 |
| Gd | | | | | | | | | | | | | | |
| Tb | | | | | | | | | | | | | | |
| Dy | | | | | | | | | | | | | | |
| Ho | | | | | | | | | | | | | | |
| Er | | | | | | | | | | | | | | |
| Tm | | | | | | | | | | | | | | |
| Yb | | | | | | | | | | | | | | |
| Lu | | | | | | | | | | | | | | |
| Hf | | | | | | | | | | | | | | |
| Ta | | | | | | | | | | | | | | |
| W ppb | | | | | | | | | | | | | | |
| Re ppb | | 0.052 | 0.014 | 0.055 | 0.213 | 0.296 | 0.014 | 0.016 | 0.024 | | | | | |
| Os ppb | | | | | | | 0.045 | 0.049 | 0.035 | | | | | |
| Ir ppb | | 0.411 | 0.114 | 0.214 | 0.021 | 2.78 | 0.042 | 0.048 | 0.016 | 0.024 | 0.019 | | | |
| Pt ppb | | | | | | | | | | | | | | |
| Au ppb | | 0.99 | 0.23 | 1.07 | 0.705 | 1.01 | 0.67 | 1.04 | 0.73 | 1.1 | 0.88 | 0.8 | 1.03 | |
| Th ppm | | | | | | | | | | | | | | |
| U ppm | | 0.168 | 0.13 | 0.115 | 0.141 | 0.33 | 0.143 | 0.15 | 0.151 | 0.138 | 0.126 | 0.16 | 0.148 | |

*technique (a) IDMS, (b) RNAA, (c ) INAA*

## Table 2. Chemical composition of Individual Glass Beads.

| | 74221,86 | | | | 74,241,143 | | | 74,241,171 | |
|---|---|---|---|---|---|---|---|---|---|
| *reference* | Hughes 90 | | | | | | | | |
| *weight (a)* | 15.5 | 12.6 | 2.8 | 3 | 3.7 | 16 | 1.8 | 2.3 | |
| SiO2 % | 39.2 | 39.1 | 38.8 | 39 | 38.7 | 38.3 | 40.4 | 39.1 | (c ) |
| TiO2 | 9.2 | 9.3 | 8.7 | 8.7 | 9.8 | 8.8 | 8.6 | 9.6 | (c ) |
| Al2O3 | 5.9 | 5.8 | 5.8 | 5.8 | 6.5 | 5.9 | 7.8 | 6.3 | (c ) |
| FeO | 22.3 | 22.5 | 22.9 | 22.8 | 23.1 | 22.9 | 21.3 | 22.6 | (c ) |
| MnO | 0.29 | 0.26 | 0.26 | 0.27 | 0.28 | 0.28 | 0.3 | 0.31 | (c ) |
| MgO | 14.5 | 14.7 | 14.9 | 15 | 12.2 | 15.1 | 12.2 | 12.8 | (c ) |
| CaO | 7.4 | 7.2 | 7.4 | 7.3 | 8.3 | 7.6 | 8.4 | 8.1 | (c ) |
| Na2O | 0.44 | 0.47 | 0.44 | 0.46 | 0.5 | 0.17 | 0.52 | 0.49 | (b) |
| K2O | 0.06 | 0.03 | 0.07 | 0.08 | 0.08 | 0.08 | 0.1 | 0.08 | (b) |
| P2O5 | | | | | | | | | |
| S % | | | | | | | | | |
| *sum* | | | | | | | | | |
| | | | | | | | | | |
| Sc ppm | 45.4 | 46.3 | 47.6 | 46.7 | 49.8 | 48.2 | 47.8 | 49.2 | (b) |
| V | | | | | | | | | |
| Cr | 4310 | 4379 | 4516 | 4447 | 4584 | 4516 | 4310 | 4516 | (b) |
| Co | 58 | 59 | 61 | 60 | 59 | 61 | 51 | 51 | (b) |
| Ni | 27 | 96 | 75 | 18 | 123 | 108 | 68 | 69 | (b) |
| Cu | | | | | | | | | |
| Zn | | | | | | | | | |
| Ga | | | | | | | | | |
| Ge ppb | | | | | | | | | |
| As | | | | | | | | | |
| Se | | | | | | | | | |
| Rb | | | | | | | | | |
| Sr | 230 | 280 | 220 | 220 | 230 | 190 | 270 | 140 | (b) |
| Y | | | | | | | | | |
| Zr | 160 | 170 | 150 | 190 | 280 | 150 | 220 | 210 | (b) |
| Nb | | | | | | | | | |
| Mo | | | | | | | | | |
| Ru | | | | | | | | | |
| Rh | | | | | | | | | |
| Pd ppb | | | | | | | | | |
| Ag ppb | | | | | | | | | |
| Cd ppb | | | | | | | | | |
| In ppb | | | | | | | | | |
| Sn ppb | | | | | | | | | |
| Sb ppb | | | | | | | | | |
| Te ppb | | | | | | | | | |
| Cs ppm | 0.04 | 0.05 | 0.15 | 0.19 | | 0.06 | 0.05 | 0.14 | (b) |
| Ba | 120 | 59 | 161 | 31 | 80 | 129 | 79 | 124 | (b) |
| La | 5.3 | 5.6 | 5.7 | 6.2 | 5.2 | 6.6 | 7.9 | 6.3 | (b) |
| Ce | 16.7 | 15.2 | 16.2 | 18.4 | 18.6 | 18.7 | 21.2 | 18.4 | (b) |
| Pr | | | | | | | | | |
| Nd | 14.9 | 16.8 | 17.5 | 15.4 | 21.7 | 19.5 | 17.2 | 19.5 | (b) |
| Sm | 6.9 | 6.7 | 6.9 | 6.8 | 7.4 | 6.8 | 7.5 | 7.8 | (b) |
| Eu | 1.72 | 1.74 | 1.83 | 2.04 | 2.14 | 1.91 | 1.81 | 2.18 | (b) |
| Gd | | | | | | | | | |
| Tb | 1.42 | 1.49 | 1.42 | 1.65 | 2.02 | 1.77 | 1.5 | 1.89 | (b) |
| Dy | | | | | | | | | |
| Ho | | | | | | | | | |
| Er | | | | | | | | | |
| Tm | | | | | | | | | |
| Yb | 3.5 | 3.4 | 3.6 | 3.6 | 4.1 | 3.7 | 4.4 | 4.4 | (b) |
| Lu | 0.39 | 0.48 | 0.5 | 0.47 | 0.49 | 0.54 | 0.46 | 0.6 | (b) |
| Hf | 5.5 | 5.9 | 5.8 | 5.5 | 6.5 | 5.8 | 6.3 | 6.5 | (b) |
| Ta | 0.96 | 1.1 | 1.2 | | 1.3 | 1.2 | 1.3 | 1.3 | (b) |
| W ppb | | | | | | | | | |
| Re ppb | | | | | | | | | |
| Os ppb | | | | | | | | | |
| Ir ppb | | | | | | | | | |
| Pt ppb | | | | | | | | | |
| Au ppb | | | | | | | | | |
| Th ppm | 0.3 | 0.3 | 0.35 | 0.04 | 0.48 | 0.22 | 0.65 | 0.77 | (b) |
| U ppm | 0.12 | | 0.22 | 0.22 | 0.34 | 0.28 | 0.12 | | (b) |

*technique (a) micrograms, (b) INAA, (c ) elec. Probe*

**Table 3: Highly Siderophile Elements in 74220 and 74001.**

| | 74220 | | 74220 | | 74001 | | 74001 | | 74001 | | 74001 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 44 - 74 micron | | 74 - 150 micron | | 44 - 80 micron | | 80 - 200 micron | | > 200 micron | | > 80 micron | | |
| | etchate | residue | etchate | residue | etchate | residue | etchate | residue | etchate | residue | *leachate* | residue | |
| Ru | - | - | - | - | 0.26 | 0.17 | 0.51 | 0.017 | 0.04 | - | - | 0.241 | (a) |
| Pd | - | 1.528 | - | 0.127 | 0.97 | 0.79 | 0.328 | 0.037 | 0.825 | 0.044 | 0.064 | 0.253 | (a) |
| Re | 0.0106 | 0.067 | 0.0264 | 0.002 | 0.013 | 0.023 | 0.046 | 0.003 | 0.0058 | 0.0008 | 0.0025 | 0.0372 | (c ) |
| Os | 0.158 | 0.0245 | 0.189 | 0.009 | 0.116 | 0.167 | 0.0074 | 0.0068 | 0.0363 | 0.0026 | 0.0067 | 0.352 | (b) |
| Ir | - | - | - | 0.015 | 0.17 | 0.134 | 0.0046 | 0.0096 | - | 0.024 | 0.0058 | 0.205 | (a) |
| Pt | - | 0.265 | - | 0.346 | 0.83 | 0.712 | 0.706 | 0.0028 | 2.75 | 0.016 | 0.05 | 0.62 | (a) |

ppb by (a) ICP-MS, (b) IDMS neg. (c ) calculated from Os isotope (Walker et al. 2004)

| | 74220 | 74241 | 74001 |
|---|---|---|---|
| Ru | <1 | 3 | <1 |
| Os | 0.7 | 0.8 | 20 |

ppb by Jovanovic and Reed 1974

| | 74220 | | 74220 | size fractions (microns) | |
|---|---|---|---|---|---|
| | 500 - 62 microns | | 500 | 62 | 20 |
| | l + e | residue | to 62 | to 20 | to 0.1 |
| Au | 0.86 | 0.274 | 0.34 | 0.605 | 1.7 |
| Ir | 0.65 | 0.21 | 0.06 | 0.28 | 0.38 |

ppb by RNAA (Wasson et al. 1976)

**Table 4: Comic ray induced activity Orange Soil.**

| | ref: | depth (cm) | 26Al dpm/kg | 22Na | 54Mn | 56Co | 46Sc | 48V |
|---|---|---|---|---|---|---|---|---|
| 74220 | Kieth 74 | ~ 6.5 | 45 | 51 | 50 | 31 | 19.1 | 13 |
| 74002 | Fruchter 78 | 0.3 | 78 | 125 | | | | |
| | | 0.75 | 85 | 142 | | | | |
| | | 1.25 | 75 | 135 | | | | |
| | | 1.75 | 71 | 110 | | | | |
| | | 2.75 | 54 | 103 | | | | |
| 74001 | | 7 | 48 | 74 | | | | |
| | | 37 | 33 | 38 | | | | |
| | | 57 | 33 | 29 | | | | |

**Table 5. Microprobe analysis of Orange Glass (groups).**

| | 74220 | 74220 | 74240 | 74220 | | | | 74001 | 74220 | 74220 | 74220 | A 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *reference* | Delano 81 | Reid 73 | Reid 73 | Prinz 73 | Carter 73 | Glass 73 | Roedder 73 | Heiken 74 | Mao 73 | Philpotts 73 | | Warner 79 |
| *# beads* | 140 | 47 | 80 | | | 19 | | inc. black | | red | black | 47 |
| SiO2 % | 38.5 | 38.55 | 38.63 | 39.2 | 38 | 39.4 | 39.5 | 38.73 | 38.88 | 38 | 40.1 | 39.2 |
| TiO2 | 9.12 | 8.87 | 8.96 | 9.4 | 8.87 | 9.3 | 8.56 | 9.46 | 8.7 | 9.6 | 9.9 | 8.9 |
| Al2O3 | 5.79 | 5.85 | 5.87 | 5.8 | 5.51 | 6.02 | 6.41 | 5.98 | 5.76 | 5.4 | 6.3 | 5.9 |
| FeO | 22.9 | 21.96 | 22 | 22.4 | 22.4 | 22.7 | 22.2 | 22.6 | 22.21 | 23.4 | 23.8 | 22.4 |
| MnO | | | | | | 0.3 | 0.32 | | 0.24 | | | 0.28 |
| MgO | 14.9 | 14.99 | 14.79 | 14.1 | 14.5 | 15.5 | 14.4 | 14.2 | 15.81 | 17.3 | 15.1 | 14.6 |
| CaO | 7.4 | 7.16 | 7.31 | 7.6 | 6.99 | 6.42 | 7.13 | 7.73 | 7.17 | 6 | 7 | 7.2 |
| Na2O | 0.38 | 0.33 | 0.37 | 0.31 | 0.39 | 0.69 | 0.51 | 0.35 | 0.42 | 0.4 | 0.38 | 0.36 |
| K2O | | | 0.08 | 0.04 | 0.06 | | 0.08 | 0.07 | 0.06 | | | 0.09 |
| P2O5 | | | | 0.04 | | | 0.05 | | | | | 0.04 |
| S % | | | | | | | | | | | | |
| *sum* | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| Sc ppm | | | | | | | | | | | | |
| V | | | | | | | | | | | | |
| Cr | 4721 | 3762 | 3762 | 4174 | 4789 | | 3558 | 4037 | 5063 | | | 4584 |

**Table 6: Halogens and sulfur in Orange Soil.**

| | Jovanovic 74 | | | | | Wanke 73 | | | Thode 76 | | Gibson 74 | | | Gibson 78 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 74220 | 74220 | 74241 | 74001 | | 74220 | 74241 | | 74220 | 74241 | 74220 | 74220 | 74260 | 74001 - 2 | 74220 |
| F ppm | 102 | 61 | 230 | <2 | (a) | 69 | 210 | (b) | | | | | | | |
| Cl ppm | 72 | 103 | 59 | 40 | | 20 | | | | | | | | | |
| Br ppb | 1580 | 420 | 800 | 180 | | | | | | | | | | | |
| I ppb | 14 | 13 | 13 | 6 | | | | | | | | | | | |
| S ppm | | | | | | | | | 420 | 940 | 560 | 750 | 1080 | 548 | 820 |

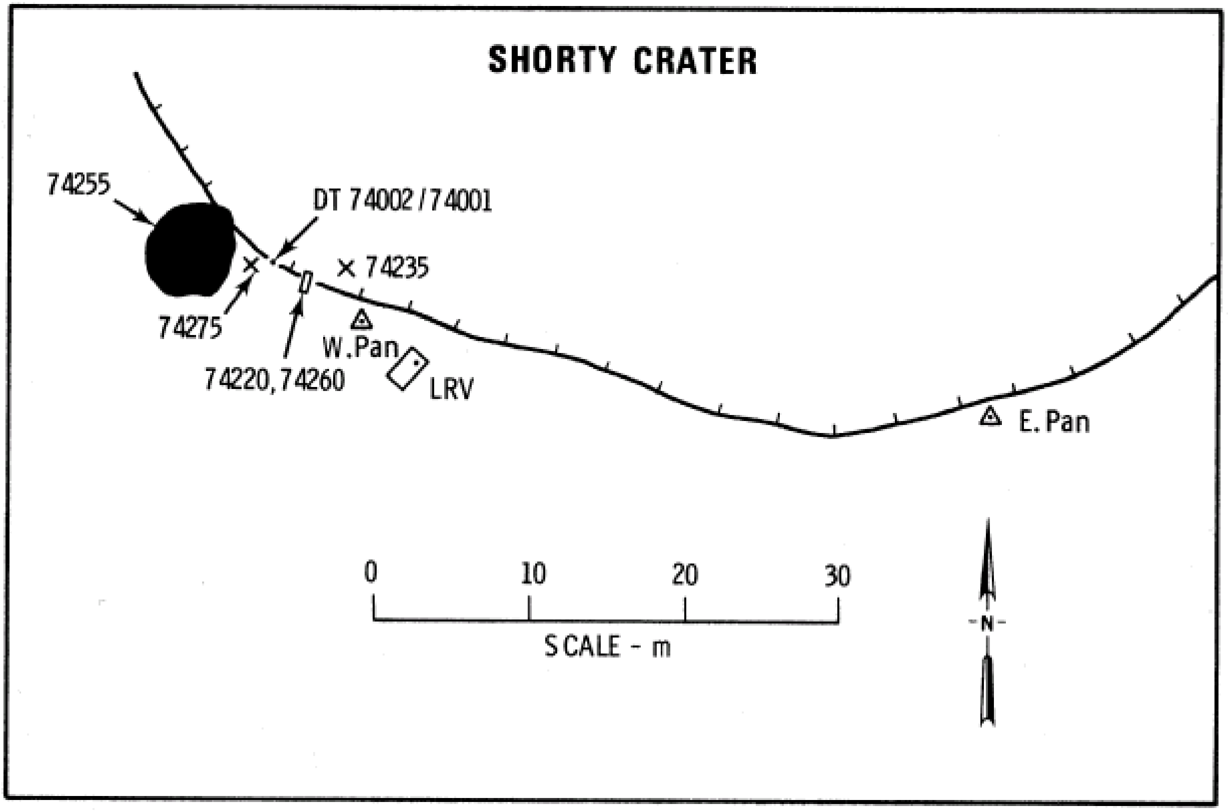


*Figure 21: Map of Shorty Crater showing locations of samples. Figure 1 was taken from the position marked W. Pan.*

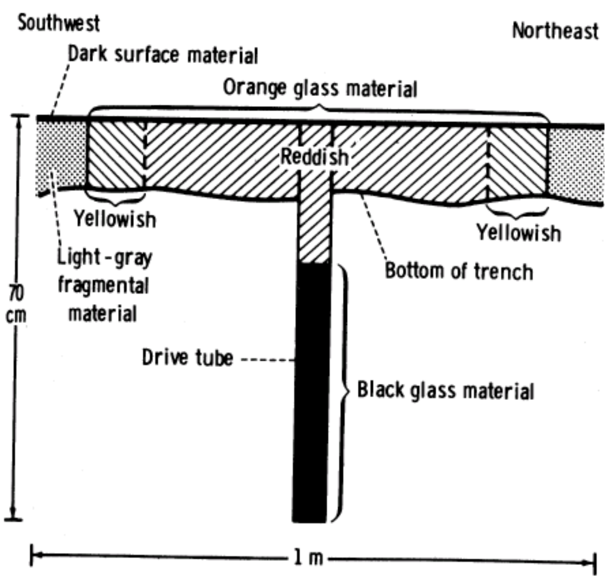


*Figure 22: Sketch of trench and core tube on rim of Shorty Crater (from Muehlberger et al. 1973). The orange soil (74220) and the core (74002/1) were taken from the middle of the trench and the grey soils (74240 and 74260) from either end. The core was from just behind the trench.*

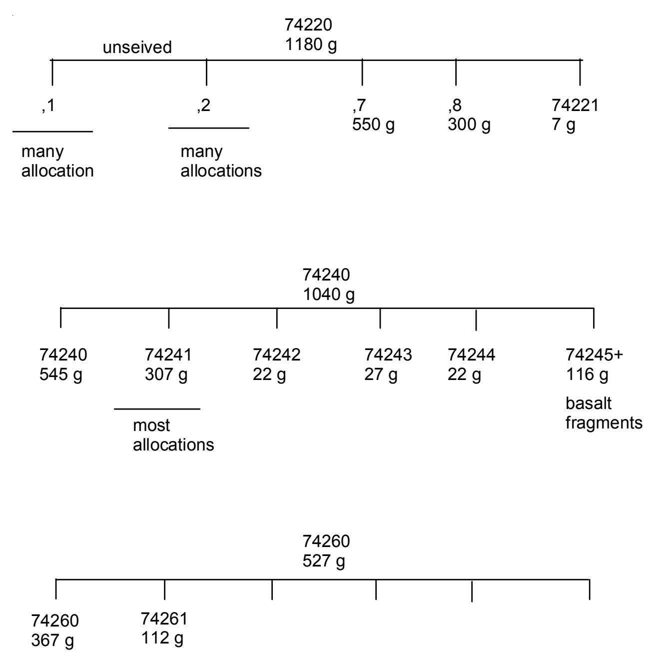


*Figure 23: Top-level flow diagram of sample weights and allocations.*

### References for Orange Soil


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