Preliminary Geological Findings on the BP-1 Simulant

The following is a summation of information and discussion between Doug Stoeser of the USGS and Doug Rickman of NASA in February and March, 2010 pertaining to the BP-1 simulant. The analytical results and the bulk of the text are from communications from Dr. Stoeser. Their form and final content as presented here are the responsibility of Doug Rickman.

The BP-1 simulant is made from Black Point Basalt Flow, San Francisco Volcanic Field, northern Arizona. The Black Point flow is about 60 miles (100 km) NNE of Flagstaff, Arizona just east of Arizona highway 89. It is over 40 km long and one of the younger flows of the San Francisco Volcanic Field (Pliocene age). In contrast the JSC-1 and -1A simulants are made from Merriam Crater, an ash cone volcano, in the San Francisco Field, and have a different composition (Carpenter, 2005).

There is an aggregate (road metal) quarry on the northern margin of the flow towards the west end (figure 1) that was used as a Desert Research and Technology Studies (Desert RATS) analog test site. The quarry site also includes piles of silt-sized washing waste which was included in the testing (Rahmatian and Metger, 2010). This silty material was also used in laboratory tests and found to have geotechnical properties similar to the LHT-2M and Chenobi regolith simulants and is being proposed as a possible simulant for geotechnical use (Rahmatian and Metger, 2010). It currently has the designation of BP-1 (Black Point 1).

Figure 1. The Black Point basalt lava flow as seen with GoogleEarth. The location of an aggregate quarry and two geochemical samples sites is also shown.

The USGS National Geochemical Database contained two whole rock analyses of the Black Point flow (table 1). The Black Point basalt is fairly alkaline (figure 2), i.e. has high total alkalis (Na2O +K2O) and chemically is typical of continental basalts. The flow also has a high Fe:Mg ratio relative to most basalts. As is the case with alkaline basalts it has a somewhat elevated TiO2 content of 2.2-2.3 percent. The high alkali content relative to lunar basalts possibly precludes the Black Point basalt from being appropriate for simulants where composition is a critical aspect but the high Fe:Mg ratio is mare like. These issues of course have nothing to do with BP-1 as a geotechnical material.

Note in figure 1 that the flow distinctly changes color laterally from black to dark brown going eastwards and is distinctly brown at it's east end, at it's toe, suggesting oxidation of the basalt in that area. The eastern W172154 analysis seems to reflect that in that it has a very high Fe_2O_3:FeO ratio relative to the W172158 western analysis. Fortunately the quarry is located near the west end and thus in a good location in regards to oxidation.

Table 1. Whole rock major element geochemistry with normative mineralogy for the Black Point flow from the USGS National Geochemical Database (http://mrdata.usgs.gov/geochemistry/ngdbrock.html).

Sample	W172158	W172154
Latitude	35.67	35.67
Longitude	-111.47	-111.35
SiO2	47.2	46.9
Al2O3	16.7	16.4
TiO2	2.3	2.2
Fe2O3	5.9	8.2
FeO	6.2	3.7
MgO	6.5	5.6
MnO	0.21	0.21
CaO	9.2	9.6
Na2O	3.5	3.4
K2O	1.1	1.1
P2O5	0.52	0.51
H2O-	0.11	0.51
H2O+	0.41	0.69
CO2	0.05	0.26
Total	99.90	99.28
FeOt	11.7	11.4
%AN	47.1	46.7

Table 1 cont.

CIPW cation normative minerals		
or	6.6	6.7
ab	30.3	31
an	27	27.1
ne	0.9	0.4
di	12.7	14.9
ol	14.2	11.6
mt	4	4
il	3.2	3.2
ap	1.1	1.1

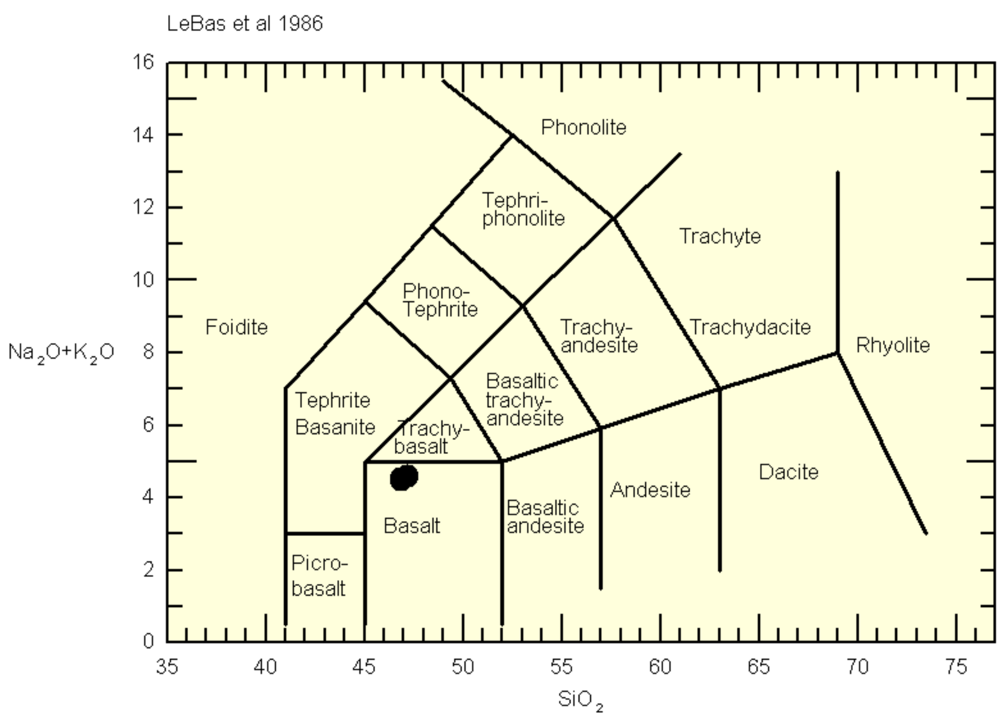

Figure 2. Total alkali vs SiO2 rock type classification diagram.

A small hand sample of the source rock was provided to Dr. Stoeser. He visually characterized it as an amygdaloidal basaltic material. The amygdules are filled with secondary minerals containing opaline silica, calcium carbonate and ferric iron minerals. The formal petrography of the Black Point basalt and the BP-1 quarry waste remains to be determined.

Under the direction of Robert Mueller, samples from 5 different 1 ton lots of BP-1 were taken. From each split a <10 µm split was provided to the USGS for XRD analysis. The results of these analyses are given in table 2. For the most part the mineralogy is typical for a basalt, plus a small amount of quartz, calcite, and hematite (Fe_2O_3). The XRD results are good down to 2-3% depending on the mineral (i.e. well separated peaks in the XRD spectrum) and thus the numbers for the minor phases are only approximate. The plagioclase fitted has the composition An_{65}, i.e. $Ca_{0.65}Na_{0.32}(Al_{1.62}Si_{2.38}O_8)$. The pyroxene augite had the composition $(CaMg_{0.74}Fe_{0.25})Si_2O_6$.

Table 2. XRD summary table for Metzger's <10µm splits of BP-1

Mineral	Bag 1	Bag 2	Bag 3	Bag 4	Bag 5	Bag All
Primary Minerals						
Plagioclase	50	53	48	49	48	48
Augite	17	13	11	15	15	14
Olivine	14	10	8	13	12	11
Nepheline	3	3	2	2	1	2
Magnetite	8	7	6	10	5	6
Total Primary	92	86	75	89	81	81
Secondary Minerals						
Quartz	3	3	0	3	3	3
Hematite	2	3	2	2	2	4
Calcite	3	5	9	1		7
Muscovite (sericite)	0	3	5	0	5	5
Halite	1	2	5	3	1	1
Bassanite	0	0	3	4	2	2
Total Secondary	9	16	24	13	8	22

Chemically the basalt is such that it shouldn't have any primary silica (quartz), note the presence of nepheline. So the quartz is almost certainly all secondary and coming primarily from vesicle fillings and possibly seams. The total secondary minerals ranges from 9-24%, which is felt to be high. They may be concentrating in the material used to make the BP-1 simulant because of the how they occur in the source rock and the way the rock is processed.

Of special note are the bassanite $CaSO_4 \cdot 0.5H_2O$ and halite, NaCl. The halite, common table salt, was confirmed by washing the material with distilled water, which removed the salt. Halite is not a constituent of basalts. Neither is bassinite. It is hypothesized that the wash water used at the quarry probably comes from a saline aquifer. With reuse of the water the dissolved salts will concentrate and eventually start to precipitate minerals.

Table 3 compares the preliminary XRD chemical analysis of the <10µm splits of BP-1 versus the database values for the flow. The higher Ca, Mg, and CO_2 values are compatible with secondary minerals as indicated by other observations.

Table 3 XRD analyses of BP-1 splits

	Bag 1	**Bag 2**	**Bag 3**	**Bag 4**	**Bag 5**	**Bag All**	W172158	W172154
Fe2O3	11	11	11	13	9	11	11.7	11.4
CaO	13	13	13	12	14	14	9.2	9.6
K2O	0	0	0	0	0	0	1.1	1.1
SO2	0	0	0	2	1	0	-	"-
SiO2	45	44	44	43	45	44	47.2	46.9
Al2O3	16	18	18	16	17	17	16.7	16.4
MgO	10	7	7	9	9	8	6.5	5.6
Na2O	3	4	4	4	2	3	3.5	3.4
CO2	1	2	2	1	2	3	0.05	0.26
Total	99	99	99	100	99	100	95.95	94.66

References

Carpenter, Paul. 2005. Characterization Strategies and Requirements for Lunar Regolith Simulant Materials. In *Lunar Regolith Simulant Materials Workshop, Jan 24-26*, Presentation. Huntsville, AL.

Rahmatian, Laila A., and Philip T. Metzger. 2010. Soil Test Apparatus for Lunar Surfaces. In *Engineering, Science, Construction, and Operations in Challenging Environments (12th) (Earth and Space 2010), March 14-17*, 15. Honolulu, Hawaii: ASCE.