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PETROGRAPHIC AND PETROLOGICAL STUDIES OF LUNAR ROCKS

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16. Abstract

Clasts, rind glass, matrix glass, and matrix minerals from five Apollo 15 glass-coated breccias (15255, 15286, 15465, 15466, and 15505) have been studied optically and with the SEM/microprobe. Rind glass compositions differ from sample to sample, but are identical, or nearly so, to the local soil, suggesting their origin by fusion of that soil. Most breccia samples contain green or colorless glass spheres identical to the Apollo 15 green glasses. These glasses, along with other glass shards and fragments, indicate a large soil component is present in the breccias. Clast populations include basalts and gabbros containing phases highly enriched in iron, indicative of extreme differentiation or fractional crystallization. Impact melts, anorthosites, and minor amounts of ANT suite material are also present among the clasts.

Tektite glasses, impact melts, and breccias from the Zhamanshin structure, USSR, have also been studied. Basic tektite glasses have been found to be identical in composition to impact melts from the structure, but no satisfactory parent material has been identified in the limited suite of samples available. Siliceous glasses (Irghizites) were found to be agglomerates of glass droplets of identical composition. Some contain vesicles filled with fragmental material of similar composition, suggesting that the siliceous Irghizites may have been formed by fusion of local soil.

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PREFACE

OBJECTIVES AND SCOPE OF WORK

The objectives and scope of work under this contract were to examine, by optical and scanning electron microscopy and by electron microprobe (SEM/EDS system), materials from the lunar highlands (impact melts and breccias) and from terrestrial meteorite impact craters. Studies in these two areas were made concurrently to elucidate the process or processes by which the surfaces of planets are formed and modified.

CONCLUSIONS

Examination of polished thin sections of five glass-coated breccias from the Apollo 15 landing site revealed both similarities and differences among them. Glass coatings on breccias from different sites differ texturally and compositionally, thus all coatings were probably not formed by fusion of the same material by the same event. Comparison with existing analyses of local soils indicated that some soils and glass coatings are compositionally identical, thus strongly supporting the conclusion that the glass coatings on the Apollo 15 samples were formed by fusion of the local soils This conclusion led to another hypothesis, as yet unproven, that the local soils were fused by smaller meteorite impact events.

The presence of glass spheres, identical in composition to the emerald green glasses found in the soil at the Apollo 15 site, in the matrices of the Apollo 15 glass-coated breccias, indicated the presence of the soil component in the breccias themselves. The soil component was also indicated by the presence of glass shards and metallic iron droplets in the breccia matrix.

Analyses of lithic clasts found in these glass-coated breccias indicated the presence of four different rock types: basalts (extrusive igneous); gabbros, norites, and troctolite (intrusive igneous); impact melts; and breccias and hornfels (metamorphic). Identified among the extrusive and intrusive igneous rocks were gabbros and basalts that have phases indicative of highly evolved igneous rocks. Ferrohedenbergite, ferroaugite, pyroxferroite, and fayalite were found along with high silica mesostasis glass that often contained (up to 8%) K_2O. The presence of these phases indicated either extreme differentiation or fractional crystallization. The lithic clasts containing these phases were most similar to those recovered from the Luna 24 landing site. Norite, impact melt, and basalt, with phases that are considerably more magnesian than the rocks discussed above, were also found, suggesting that the Apollo 15 site may be underlain by a highly differentiated igneous complex.

Examination and analysis of tektite glasses, target rocks, and impact melts from the Zhamanshin structure, USSR, led to the conclusion that of the two types of tektite glass analyzed, one type, of basic composition, was impact melt, identical to melts found at the crater. No parent rocks have yet been identified because of the paucity of country rock samples. Siliceous tektite glasses (Irghizites) were found to be similar in major and trace element composition to tektites of the Australasian strewn field. It is hypothesized that they were formed by agglomeration of glass droplets, and they appear to have incorporated mineral (soil?) fragments in voids or vesicles during their formation. Analysis of these vesicle fillings pointed up some striking similarities between the two, but there were also differences. The evidence suggests that the siliceous Irghizites were formed by fusion of the soil, but this hypothesis remains to be tested.

RECOMMENDATIONS

It is recommended that samples of glass-coated breccias be obtained and that clasts, rind glass, and matrix be separated and analyzed for lithophile and siderophile trace elements, and Ar, Rb, and Sr isotopes. Highly evolved rock types should be analyzed isotopically and for lithophile trace elements.

These analyses would help establish the origin of the glass coatings and the relationship between coatings, breccia host, and soils. Age and trace element composition of the highly evolved rock types (those containing pyroxferroite, fayalite, silica minerals, and high K glass mesostasis) are essential to establishing their origin and differentiating between impact melts and indigenous liquids. In addition, age and isotopic data for high K clasts will contribute to knowledge relating to the origin of KREEP.

Further sampling should be done at the Zhamanshin crater, both for country rocks and impact melts, to provide a reasonable suite of samples from which to work. Soil samples should be taken and analyzed for major, minor, and trace elements for comparison with siliceous Irghizites to test the soil fusion hypothesis.

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INTRODUCTION

As outlined in the statement of work under contract NAS5-24163, three areas of study were to be undertaken, as directed by senior GSFC scientists: 1) petrological studies of meteorites, 2) petrological studies of impactite materials, and 3) petrological studies of lunar breccias and shock-melted rocks. No meteorites were designated for study during the past contract year, therefore, the work concentrated on the latter two areas.

This year, studies of lunar breccias and shock-melted materials concentrated on Apollo 15 glass-coated breccias. Breccias from five locations at the Apollo 15 landing site were chosen for study, and considerable work has been done on these samples.

Concurrent with the study of Apollo 15 glass-coated breccias, work continued on Apollo 16 consortium breccia 61175. The findings were published in the Proceedings of the Eighth Lunar Science Conference (Winzer *et al.*, 1977a). Some preliminary work was also done on a specially prepared sample for laser probe $^{40}Ar/^{39}Ar$ age analysis.

This year's study of terrestrial meteorite impact craters focused on the Zhamanshin structure in the USSR. This crater is the subject of a consortium effort and is of unusual importance due to the presence of tektites within the crater itself. Elucidation of the relationship of these tektites to the crater, and to the impact process, has considerable bearing on the origin of homogeneous glasses found on the earth and on the moon. Discussions of this crater, and Tenoumer Crater, Mauritania, were presented at the August annual meeting of the Meteoritical Society (Florensky *et al.*, 1977; Winzer *et al.*, 1977b).

LUNAR SAMPLES

PETROLOGICAL STUDIES OF LUNAR BRECCIAS AND SHOCK-MELTED ROCKS

Apollo 16 Consortium Breccia 61175

Results of petrographic, major, and trace element studies of consortium breccia 61175 have been published (Winzer et al., 1977a). New work on this rock will involve further analyses of clasts in the matrix and of a specially prepared specimen designated for laser-probe $^{40}Ar/^{39}Ar$ age analysis (by Schaeffer). Due to problems with specimen preparation, we have not been able to do any analyses on this sample to date.

Apollo 15 Glass-Coated Breccias

As part of our research during the 1976-77 contract year, studies were begun on 15255, a glass-coated fragment-laden impact melt that had been located near Spur Crater on the slope of Hadley Delta (Station 6; Nava et al., 1977). As an outgrowth of this work, several other glass-coated breccias from the Apollo 15 site were chosen for further study. Other samples were chosen for two principal reasons: 1) to attempt to discover the origin of the glass coatings, which, during initial examination, appeared remarkably similar, and 2) to look for lithic fragments (clasts) containing the iron-rich phases -- pyroxferroite and fayalite, xenocrysts of which had been found in the 15255 breccia. The breccias chosen for further study were 15286, 15465, 15466, and 15505. 15286 was also located on the Hadley Delta at Station 6, but was collected from the inner bench of a 12-m diameter crater. 15465 and 15466 were collected from the rim of

Spur Crater at Station 7, and 15505 is a sample from the ejecta blanket of a 15-m diameter crater at Station 9. Therefore, all five samples were from either the inside of, on the rim of, or in the ejecta blankets of smaller craters at the Apollo 15 site.

Glasses

All breccias chosen for study have glassy matrices (with different proportions of glass to mineral and lithic fragments) and have glass coatings on one or more sides (Table 1). 344 analyses of rind glass, internal (matrix) glass shards and spheres, and mesostasis glass were made by the SEM/EDS method (Winzer *et al.*, 1977a). Each group of glasses will be discussed separately.

Glass Coatings

The glass coatings found on all the breccias are grossly similar in appearance. All adhere to the outer surfaces of glassy-matrix breccias, forming an uneven, vesicular layer. Vesiculation of the glass coatings varies from sample to sample, and also within a single sample. 15255 has a thin layer of vesicular glass separating the bulk of the glass coating from the breccia matrix. This layer is considerably more vesicular than the bulk of the glass, and the vesicles are considerably smaller (Nava *et al.*, 1977; Winzer *et al.*, in press, attached). On samples 15466 and 15505, this layer is discontinuous or absent.

The bulk portion of the glass coatings is also vesicular, and each coating differs from the others in the number and size of vesicles. 15255 contains the highest number of open vesicles, and 15466 has the lowest number. 15286 is a special case; vesicles in the glass coating of this

TABLE 1

Modal Analyses of Glass-Coated Breccias

Sample Identification	Glass Rind	Opaque Chondrules in Rind	Crystals and Clasts in Rind	Matrix	Glass Fragments	Extrusive Clasts	Plutonic Clasts	Impact Melt and Breccia Clasts
15505,48				70.62	4.00	2.78	1.43	5.40
15505,80	9.30			51.27	8.17	7.32	1.83	1.83
15466,22	42.61	0.31	6.62	33.08	0.46	6.15		1.69
15465,35	54.10				0.76			40.76
15465,53				66.41	2.10	6.30		2.25
15465,54				56.20	5.93	7.85	4.54	4.36
15286,29				67.05	3.60	13.15		4.50
15286,33	67.79	0.23			1.76	3.02	0.17	11.27
15255,38	10.32			48.13	8.31	6.88		4.58
15255,77	8.06			42.32		3.40		16.80

Sample Identification	Glass Chondrules	Plagioclase	Clino-pyroxene	Ortho-pyroxene	Olivine	Opaques	Primary Crystals in Rind Glass	Total Points Counted
15505,48	0.42	3.12	8.35	1.77	0.59	1.52		1186
15505,80	0.56	8.31	5.35	1.41	1.27	3.38		710
15466,22		4.77	1.69	1.08	1.08	0.46		650
15465,35		0.76	0.38		0.19		3.05	525
15465,53	1.95	13.04	4.05	1.20	0.45	2.25		667
15465,54	1.75	12.57	4.01	0.87	0.70	1.22		573
15286,29	1.98	4.50	2.70	0.72	0.18	1.62		555
15286,33		0.11	0.28	0.23	0.23		14.91	1757
15255,38	0.57	10.32	5.73	3.44		1.72		349
15255,77	1.07	10.87	10.29	3.11	2.14	1.94		1030

sample are irregular in shape. Some appear to have been deformed by later plastic flowage of the glass, and some appear to have been formed by droplets of glass that have adhered together, leaving an irregular void between them. In this manner, the glass coating on 15286 strongly resembles tektites from the Zhamanshin structure, USSR (discussed later in this report).

The Apollo 15 glass coatings also contain variable amounts of fragmental material (xenocrysts and xenoliths). Most of the mineral fragments are feldspar, pyroxene, and olivine, in that order of abundance. Droplets of metallic iron are found in all of the glass rinds, and complex droplets of metallic iron and a sulfide mineral are found in 15286 and 15266.

Lithic "clasts," principally breccia fragments similar to the host breccia, are found in some of the coatings. 15286 contains the most lithic and mineral fragments, and both 15286 and 15466 contain lithic fragments up to 0.5 mm in diameter. It cannot be conclusively established that these lithic fragments broke off from the host breccia. In some cases, in the plane of the thin section, the fragments are completely separated from the host by glass. Flow lines in the glass around the clasts indicate that they were incorporated into the coating while the glass was still sufficiently viscous to flow.

In two of the glass coatings, 15466 and 15286, some devitrification or crystallization has occurred. Small rims, or coronas, appear on included feldspar grains in 15466; but no coronas occur on the larger lithic fragments included in the glass. 15286 is a special case among all the glass coatings studied so far, in that it has undergone a small amount of crystallization. Crystallization occurs around fragments and near the glass-breccia boundary as well as in areas removed from fragmentary material. Crystallites of olivine occur in dendritic patterns (Fo_{76}-Fo_{78}) or as elongated crystals of chain or hopper form (Fo_{78}-Fo_{83}). No pyroxenes or feldspars were found, and the occurrence of pyroxenes suggested by Wosinski et al. (1973) was not confirmed. The glass coating on 15286 is the most heterogeneous of the four studied.

Matrix Glass

The composition and occurrence of the matrix glass in all of the samples studied is highly varied. Glass occurs as shards, spheres, irregular patches, and in association with crystalline material. Matrix glass principally occurs as patches of irregular shape and varied size. A typical occurrence is shown in Figure 1, a portion of the matrix of 15466,22. The irregular, vesicular glass in the center of the photograph surrounds and includes mineral fragments and shards of glass. This type of glass, which may be vesicular or nonvesicular, appears to be the binder for the entire matrix. Figure 2, a photograph of the matrix of 15286, shows other typical matrix glass occurrences: a glass "shard" with olivine crystallites that are indicative of rapid cooling, irregular glass fragments, one or two very small droplets, and vesicular glass that includes anhedral feldspars and ilmenite. These vesicular glasses are interesting because their texture resembles that of the rind glasses.

Glass Spheres

Glass droplets with spherical cross sections occur in all the breccia samples, but are concentrated in 15465 and 15286. These glass spheres vary in size from 5 µm to over 200 µm, and vary somewhat in shape. The most common shape is circular (in cross sections), but elliptical and egg-shaped

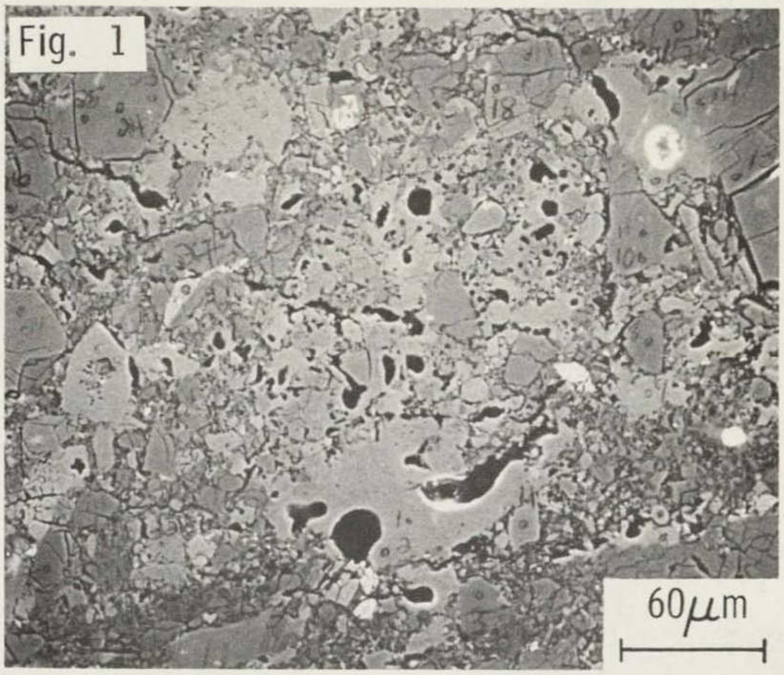

Figure 1. Scanning electron photomicrograph of a portion of the matrix of 15466,22. Vesicular glass in the center of the photomicrograph is similar in texture but different in composition than the rind glass.

Figure 2. Scanning electron photomicrograph of a portion of the matrix of 15286,29. Note partly devitrified shard in upper right and vesicular rim on mineral fragment along the lower edge.

forms are also found. All such glasses are homogeneous and lack crystallites or vesicles. Most are colorless or reddish-brown in thin section. Many of the glass spheres have been broken, and only fragments showing curved portions are left.

Chemistry of the Glasses

Rind glass, matrix glass, mesostasis glass, and glass spheres were analyzed by the SEM/EDS method. The results of the 344 analyses done so far are plotted in Figure 3. Matrix glasses -- including shards, partly crystalline fragments, and vesicular glasses -- define two fields on a plot of MgO + FeO against Al_2O_3. The main trend shows the plagioclase control, with MgO + FeO decreasing with increasing plagioclase (Al_2O_3) content. The second, minor trend has glasses with generally lower FeO + MgO for the same amount of aluminum as in those of the major trend. Glasses in this group generally contain more SiO_2 and alkalies (Na_2O and K_2O) than glasses of the main trend. The glasses found in the high SiO_2, high K_2O + Na_2O, lower MgO and FeO group are generally the mesostasis glasses from the highly differentiated clasts discussed in the next section of this report. Mesostasis glasses occur in both trends, generally paralleling the matrix glass compositions, suggesting that some of the matrix glasses may be disaggregated mesostasis.

Almost the entire range of reported Apollo 15 glass and whole-rock compositions can be found in the glasses of these few breccias, indicating their complexity and extreme heterogeneity.

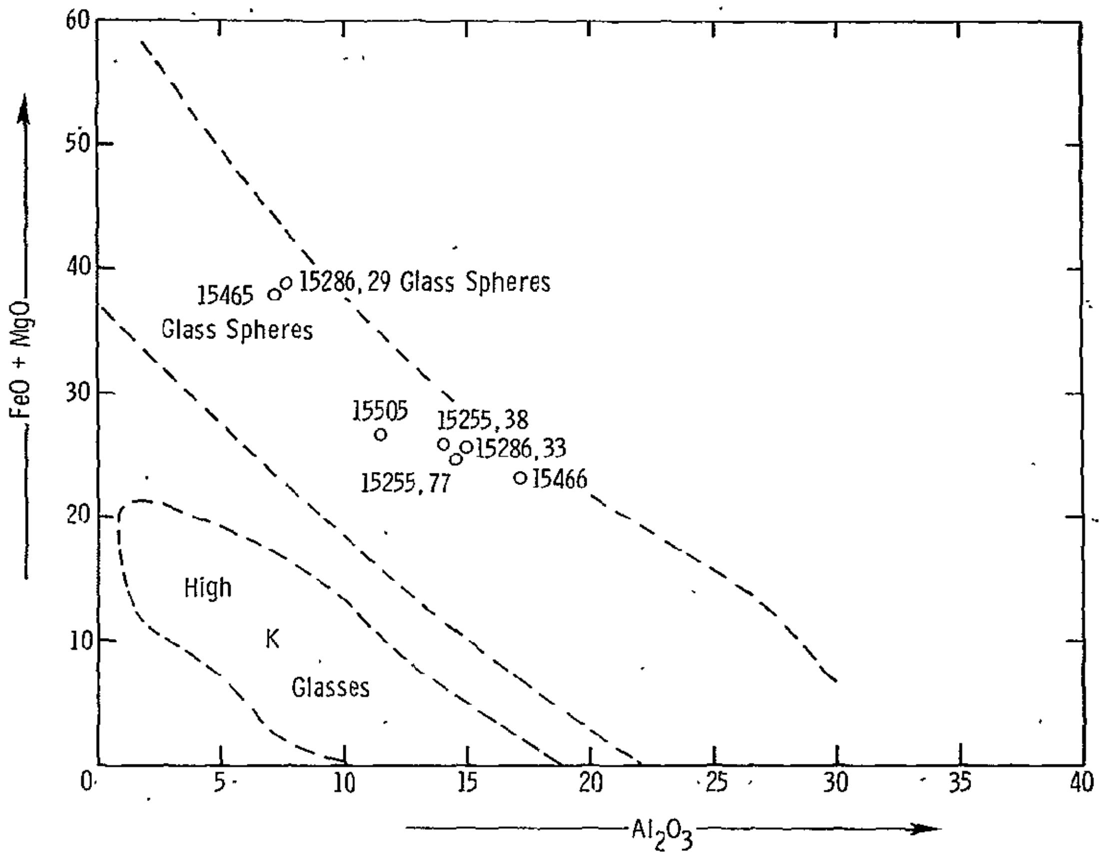

Figure 3. Electron microprobe analyses (SEM/EDS system) of glasses from Apollo 15 glass-coated breccias.

APOLLO 15 BRECCIA CLASTS

All samples contain some lithic clasts, and these clasts have a wide range of textures, compositions, and, quite probably, origins (Table 1). Analyses of several clasts from each of the five glass-coated breccias have been completed. Samples from each locality will be discussed independently in this section, and the results will be summarized at the end of the section.

15255

We have completed analyses of two polished thin sections of this rock (15255,38 and 15255,77). 15255 generally had fewer clasts that were large enough to classify than the other breccia samples; however, it must be emphasized that these sections may not be representative of the whole rock.

Identifiable clasts in 15255 include basalts, impact melts, micro-gabbros, breccia, and one troctolite. The results of electron-probe micro-analyses (SEM/EDS system) of mineral phases from 14 clasts are presented in Figures 4 and 5. Basalts are identifiable as hyalocrystalline clasts with bladed euhedral plagioclase (often zoned, see Figure 5), anhedral pyroxene, and olivine. No fragmental material (xenocrysts) appears in these samples. The basalts also show the greatest range of compositions of any of the rock types represented in the clast populations. Pyroxenes range, in single samples, from subcalcic augites or magnesian pigeonites to ferroaugite or ferrohedenbergite. Pyroxferroites were not found in any of the clasts, but were found as fragments, associated with cristobalite, in the matrix. The basalt clasts contain mesostasis glass, which is also extremely variable in composition (ranging from 37% SiO_2 to 72% SiO_2), and contains up to 4% K_2O

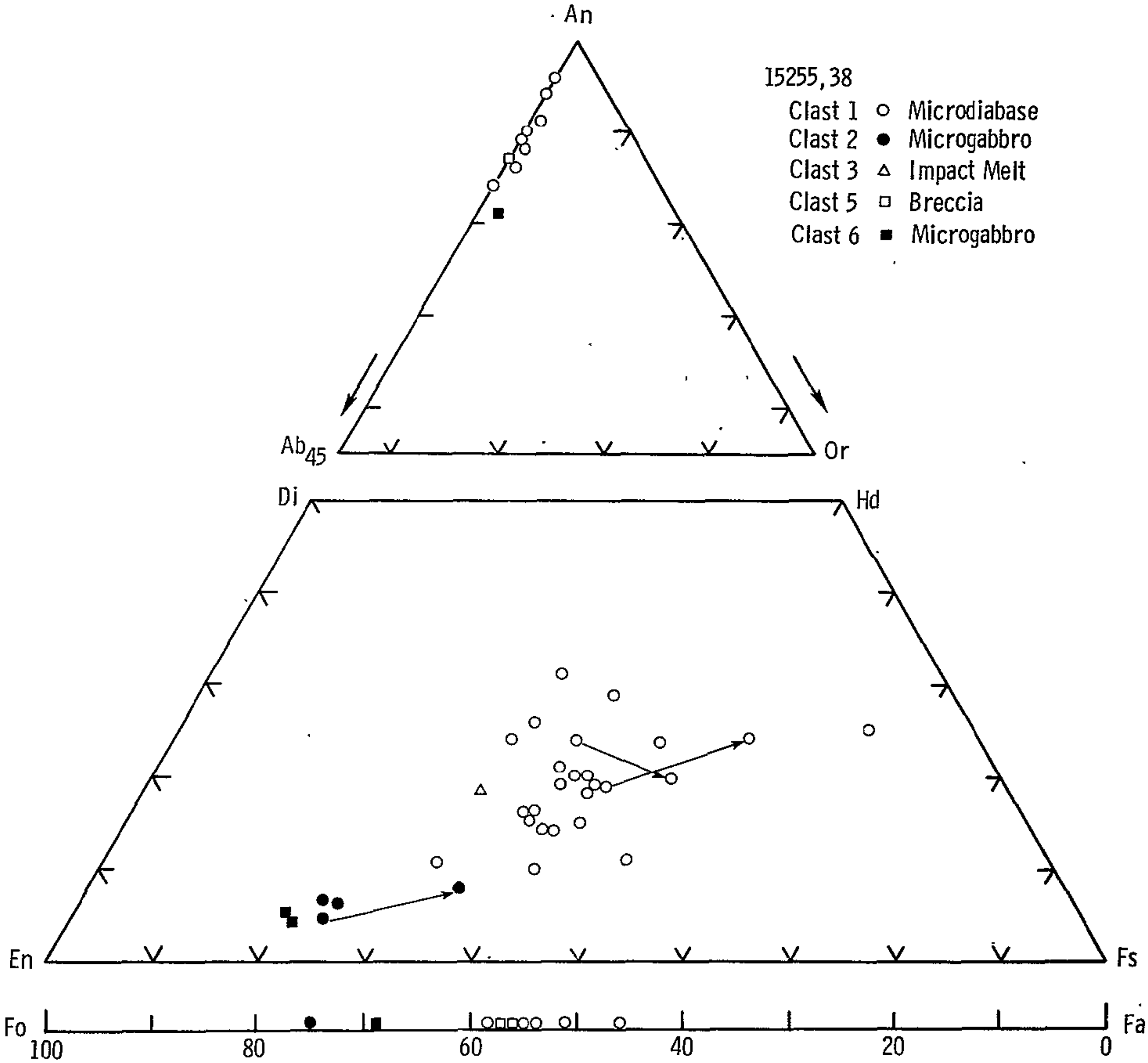

Figure 4. Electron microprobe analyses (SEM/EDS system) of plagioclase, pyroxene, and olivine from clasts in 15255,38.

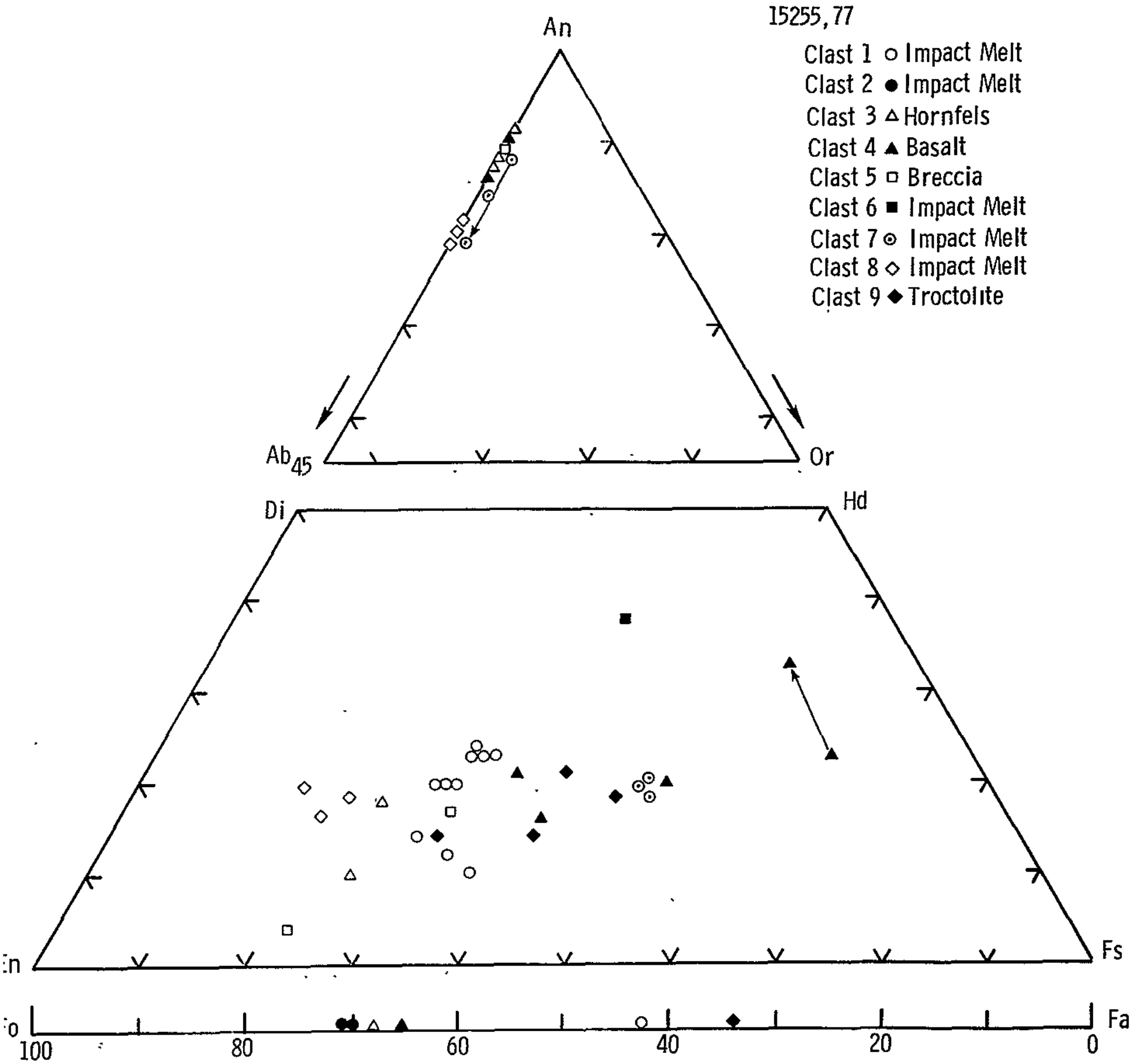

Figure 5. Electron microprobe analyses (SEM/EDS system) of plagioclase, pyroxene, and olivine from clasts in 15255,77.

(in the high silica glasses). The basalt clasts contain little ilmenite. Clasts of impact melt are highly variable texturally, and are identified on the basis of texture and chemistry. Texturally, impact melts range from holohyaline to hyalocrystalline. Both xenocrysts and xenoliths can occur in a clast, but some impact-melt clasts contain neither. Most samples that contain no xenocrysts or xenoliths are irregularly shaped glasses containing quench olivines. Minerals crystallizing from the glasses indicate a range of cooling rates, and all phases show a considerably more restricted range of compositions than those from the basalts. The minerals in the impact melt are more magnesian in composition than those in the basalts, although the most magnesian phases in the basalts overlap impact-melt phase compositions.

Mesostasis glass from the impact melts is more basic, and less variable in composition, than that of the basalts. Where a clear mesostasis is not present, such as in the quenched glasses or in the more glassy melts, more variation can be seen.

Plutonic igneous rocks are less common than either basalts or impact melts in 15255. Two microgabbro clasts and one "troctolite" clast were found, along with more numerous "anorthosite" clasts. The troctolite and the anorthosites are almost too small to be identified conclusively as definite rock types, because their relatively coarse grain size means that only a few crystals are present. All could conceivably be pieces from the same rock.

The plutonic rocks are differentiated from basalts and impact melts by their more equigranular texture, consisting of subhedral equant plagioclase and pyroxene of about the same size, anhedral olivine, euhedral spinel (chromite), and ilmenite. Mesostasis glass is absent. Plutonic igneous rocks have smaller ranges in phase composition than the basalts, but about the same range as phases in the impact melts. The compositions of the phases generally overlap those of the impact melts, except for the troctolite, which contains a very iron-rich olivine.

Several breccia clasts were also found in 15255. These clasts are similar in that they are dominated by plagioclase with an An content around 90. The breccia clasts contain few ferromagnesian minerals; those that are present are olivine and pyroxene. These clasts appear to be brecciated anorthosites, and not clasts of breccia similar to the matrix. These breccias lack glass spheres, shards, partly devitrified glass, and droplets of metallic iron found in the matrix.

One hornfels clast was found in 15255,77. This clast contained unzoned anhedral olivine and pyroxene of restricted composition in a larger mass of anhedral plagioclase, also of restricted composition (An_{87}-An_{91}). The clast has been mildly shocked enough to cause fracturing of the plagioclase and distortion of the plagioclase twins. The texture of this clast is similar to that of hornfelses from Apollo 16 sample 61175 (Winzer _et al._, 1977), and thus seems indicative of a metamorphic event.

15286

One thin section from this sample (15286,29) was examined in detail, and five clasts were analyzed. Clasts in 15286,29 differ from those in 15255, since no 15286,29 clasts had phases showing a high degree of iron enrichment. 15286 and 15255 were collected from sites only a few meters apart, but 15286 came from the inner rim of a small crater, and 15255 was from the ejecta blanket. It is not known at this time whether or not this difference in location is the controlling factor producing the difference in clast population. A solution will require more detailed chemical and isotopic analysis.

The clast population of 15286,29 includes microdiabase, microgabbro, breccia, and impact melt (Figure 6). One clast, #3, appears basaltic in texture, but contains considerable glass and does not show the degree of iron enrichment that is shown by the basalt clasts in 15255. The pyroxenes in this clast are the most iron-enriched of all the clasts present in 15286,29, and they show the greatest compositional range, a characteristic which appears to be true of lunar basalts in general. Clast 3 contains high silica glass with 5% K_2O, which is similar to mesostasis glasses from the ferrohedenbergite-bearing basalts found in 15255. It may be that this rock was quenched before more iron-rich phases had time to crystallize.

Clast 1 is somewhat coarser than clast 3, and shows even less iron enrichment than clast 3; however, this clast contains several needle-like areas of mesostasis glass with SiO_2 > 70% and K_2O up to 7.5%. This rock has a plutonic igneous texture and is partly brecciated. It may also be a basalt that did not contain sufficient iron to form fayalitic olivine or ferro-pyroxenes.

Clast 2 is a porphyritic gabbro, with one large (400-μm) euhedral plagioclase phenocryst in a matrix of olivine, enclosed by pyroxene (pigeonite and enstatite). Small subhedral ilmenites are scattered throughout the clast. The pyroxenes in clast 2 are, like the ones in clast 1, both calcic and subcalcic, and appear intermixed with one another rather than as rims or as zoned grains. The pyroxenes and the olivine in this gabbro clast are quite magnesian, a trend generally found in rocks of the ANT suite, except at the Luna 24 landing site (Barsukov, 1977).

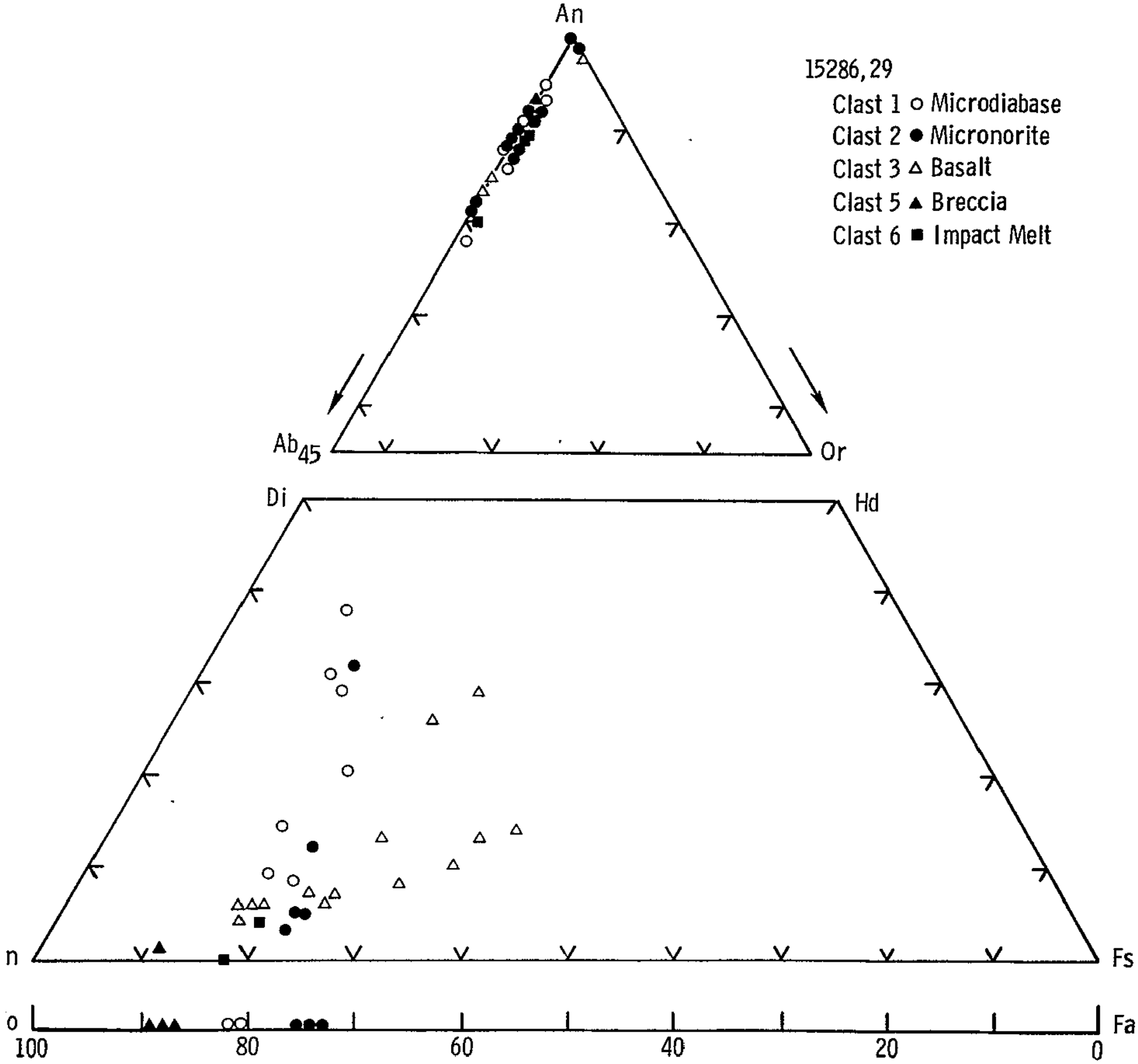

Figure 6. Electron microprobe analyses (SEM/EDS system) of plagioclase, pyroxene, and olivine from clasts in 15286,29.

The remaining clasts are glassy matrix breccia and impact melts. Impact melts in 15286 contain a high proportion of glass, and phases crystallizing from the melts are magnesian and of restricted composition. Glasses from impact melt clasts are also of generally restricted composition and are considerably more basic than the mesostasis glasses of the basalt and microdiabase clasts.

15465

One thin section of 15465 has been analyzed in detail, and two clasts and one polycrystalline fragment have been analyzed so far (Figure 7). Clast 2 is the most interesting of the two, being a relatively coarse-grained (up to 2 mm) basalt. Lath-shaped plagioclase (An_{75}-An_{82}) up to 2-mm long occurs as a few large grains. Irregularly shaped, anhedral pyroxene (ferro-augite to subcalcic ferroaugite) occurs as grains up to 1.5-mm long, enclosing glass with up to 80% SiO_2 and 7.8% K_2O. Glass compositions in this rock are highly variable, ranging from 32% SiO_2 (an ilmenite-rich mesostasis with very small ilmenite crystals) to 82% SiO_2 in a glass enclosed in subcalcic ferro-augite. Small, needle-like ilmenites are scattered throughout the clast, completing the mineralogy. Clast 4 is a finer-grained clast than clast 2, with more equant plagioclase that has a higher An content (An_{88}-An_{97}). A few small, angular pyroxenes that show the same compositional range as the pyroxenes in clast 2 complete the mineralogy of this clast. Clast 4 pyroxenes have a lower calcium content overall, and appear as augites and subcalcic ferroaugites that approach pyroxferroite composition. No glass was found in this sample.

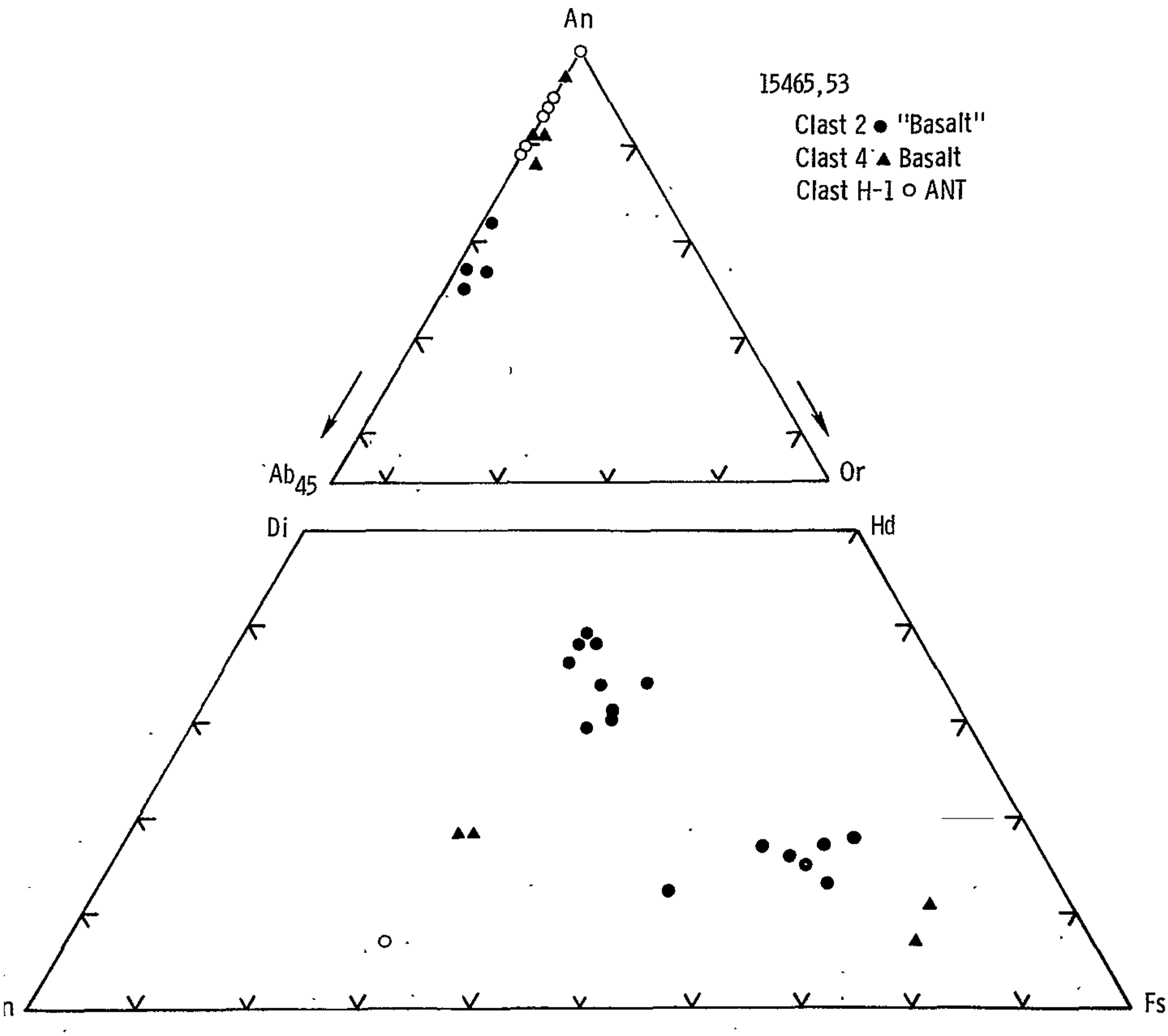

Figure 7. Electron microprobe analyses (SEM/EDS system) of plagioclase, pyroxene, and olivine from clasts in 15465,53.

15466

One thin section from 15466 (15466,22) has been examined in detail. This sample contains clasts with the widest range of phase compositions of any of the breccia samples studied. Seven clasts were studied in detail, and the results of electron microprobe analyses of phases (SEM/EDS system) are presented in Figure 8.

Of the seven clasts analyzed, three are impact melts, two are basalts, and two are ANT suite rocks, one of which is heavily shocked.

The two basalts studied show a pattern of iron enrichment similar to that of basalts from 15255 and 15466. These two basalt clasts (clasts 2 and 4) are texturally similar, with subhedral to euhedral pyroxenes and subhedral to anhedral plagioclase. The proportions of plagioclase to ferromagnesian minerals is higher than that of many of the other basalt clasts analyzed, but, although brecciated, these clasts do not contain xenocrysts, which are indicative of impact melts. Ilmenite is an accessory mineral in both clasts.

Clasts 2 and 4 differ significantly in their mesostasis glass compositions. Clast 2 contains mesostasis glasses with up to 78% SiO_2 and 6.6% K_2O, which is similar to the mesostasis glasses in other basalt clasts containing iron-rich pyroxenes or olivines. Clast 4 differs in that K_2O only reaches 1.9%, although the SiO_2 contents range up to 82%. Glasses from the mesostasis of clast 4 contain two to three times as much calcium as those of clast 2.

Plagioclase compositions from clast 2 show the greatest range of any yet found in these Apollo 15 breccias, ranging from An_{55} to An_{86}. The range in plagioclase compositions in clast 4 is smaller, An_{80} to An_{100}, with the higher An content presumably reflecting the higher overall calcium content.

Impact melt clasts from 15466,22 are all of the rapidly quenched type, with glass matrices of relatively uniform composition and a relatively

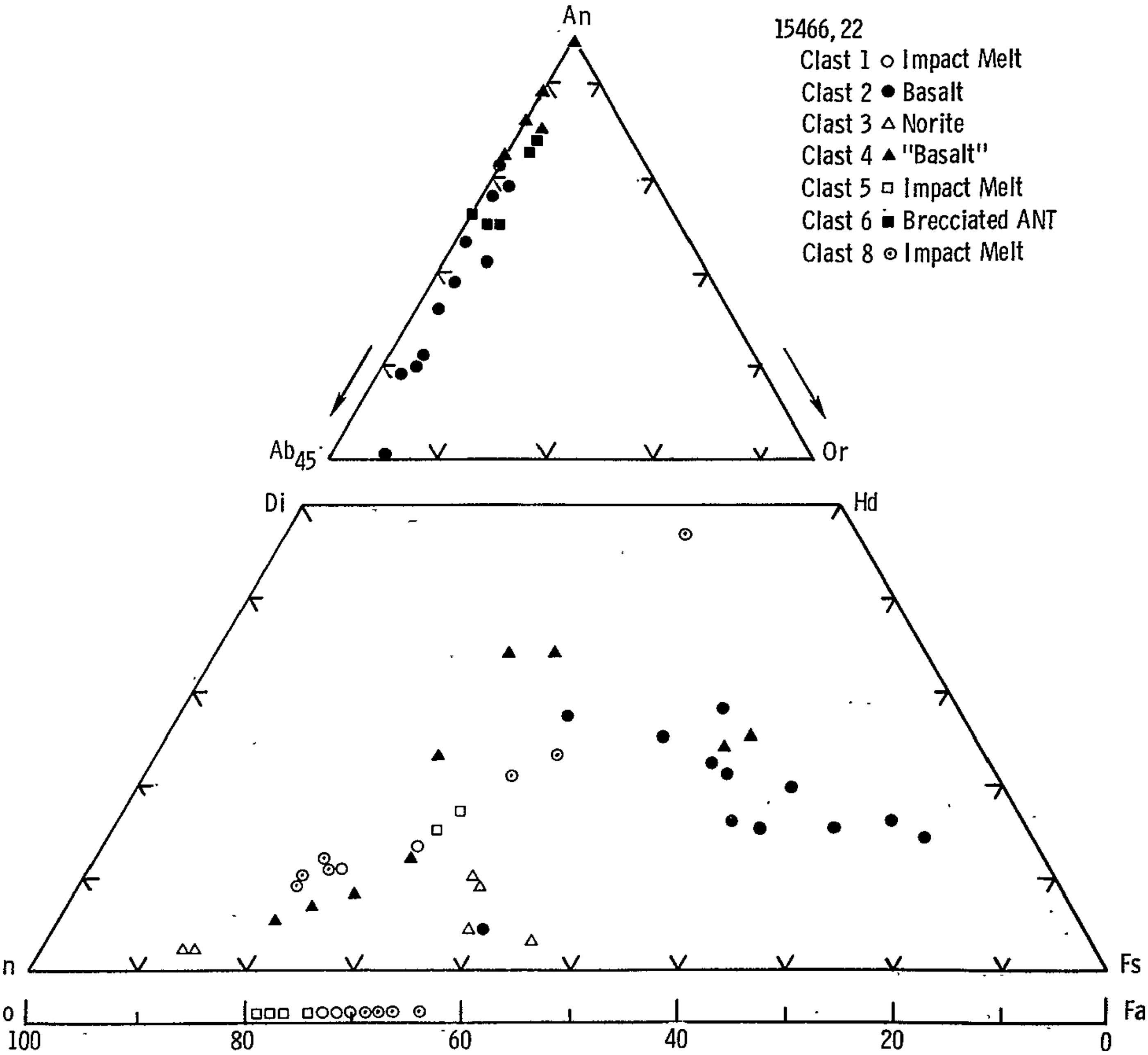

Figure 8. Electron microprobe analyses (SEM/EDS system) of plagioclase, pyroxene, and olivine from clasts in 15466,22.

restricted range of compositions of the mineral phases. All three impact melts contain both olivine and pyroxene. Both are magnesian, although they are not as magnesian as those found in impact melts from the Apollo 16 landing site (Winzer et al., 1977). Olivines are the chain or hopper type, 1-to-5-µm across and 20 or more times that in length. Pyroxenes tend to be plumose and, as with the olivines, considerably elongated.

The two plutonic igneous clasts found in 15466 are a coarse-grained (300-µm) norite consisting of ortho- and clinopyroxene, plagioclase and ilmenite (clast 3), and a brecciated anorthosite (clast 6) that consists entirely of plagioclase, maskelynite, and glass. Pyroxene compositions in the norite show a considerable range in Mg and Ca contents, from En_{57} to En_{85} and from Wo_2 to Wo_{10}.

15505

15505,80 contains the only lithic clast that has pyroferroite as a phase within it. This rock also contains a clast with the most iron-rich olivines yet found in these breccias (Fo_{12}) (Figure 9).

Clast 1 has the most unusual texture of the four clasts studied, and is the clast containing the most iron-rich olivines. The clast consists of relatively large (150-200-µm) anhedral augite and ferroaugite grains with a partly crystalline "mesostasis" comprising 15-20% of the rock. The matrix consists of an anhedral, interlocking network of higher calcium, lower iron pyroxenes, similar in composition to the larger pyroxenes that make up the bulk of the clast. Interspersed throughout this "network" are euhedral to subhedral ferroaugites and anhedral to subhedral olivines (Fo_{12}). Minor ilmenite completes the phases present, the remainder of the matrix is basic

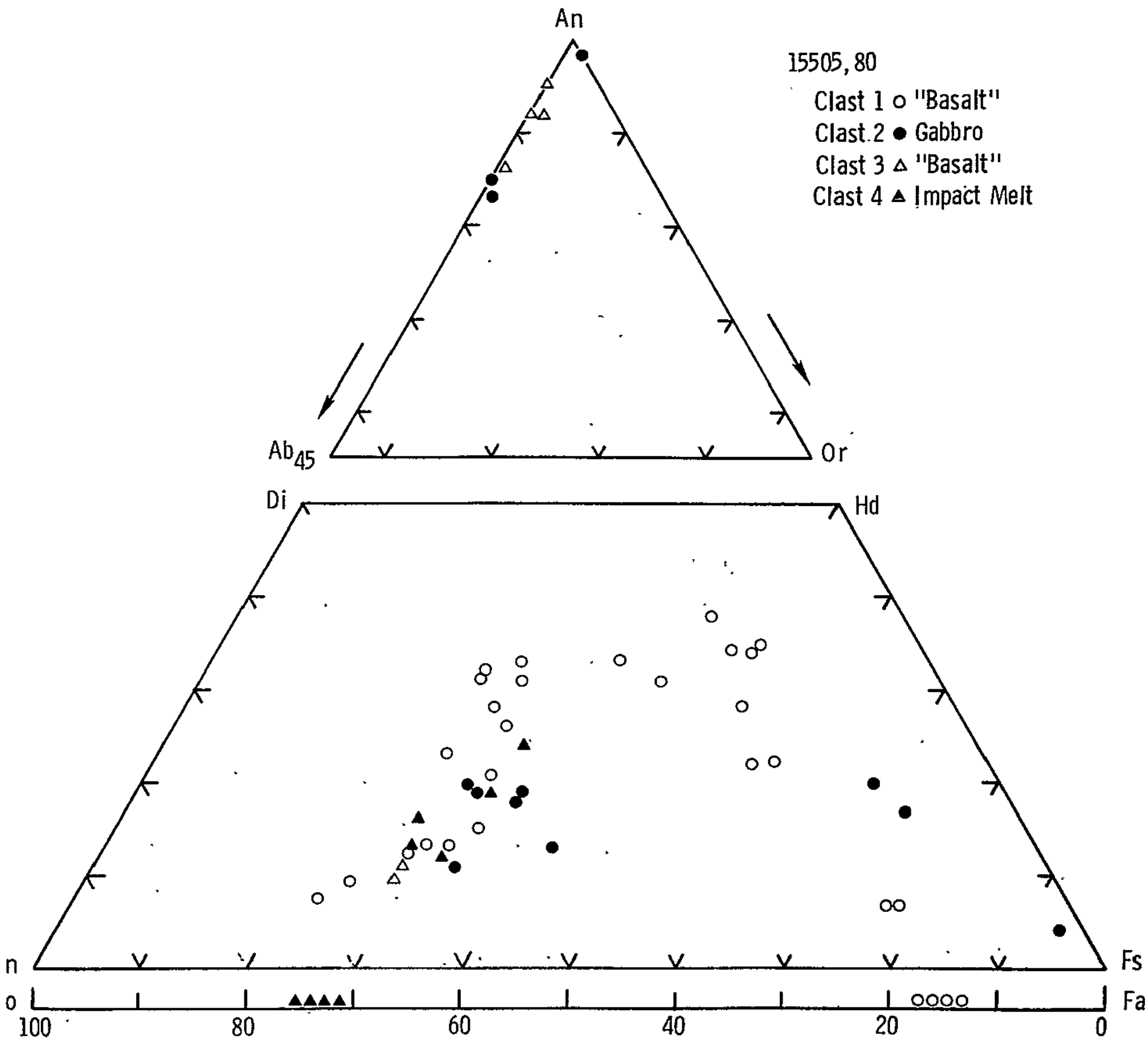

Figure 9. Electron microprobe analyses (SEM/EDS system) of plagioclase, pyroxene, and olivine from 15505,80.

glass (SiO_2 ~ 50-55%, low K_2O). A few areas in this glass are highly siliceous (to 85%), with or without K_2O. Two areas have > 0.3% K_2O. This rock lacks feldspar, and could properly be called a pyroxenite; however, the mesostasis suggests that this was not a plutonic rock.

The composition and texture of clast 2 is similar to clast 1, except that mesostasis is virtually absent in clast 2. The pyroxene compositions are less calcic than those of clast 1, and clast 2 contains feldspar. The An contents of feldspars from clast 2 are surprisingly high ($An_{83} \rightarrow An_{98}$) for a rock with this degree of iron enrichment in the pyroxenes. Interstitial glasses, where present, may have SiO_2 contents of up to 85%, with K_2O > 3%. Na_2O is virtually absent from both clast 1 and clast 2 glasses, perhaps explaining the absence of the albite molecule in the plagioclase feldspars.

Clast 3 is a "basalt" consisting of lathlike feldspars (An_{86}-An_{95}) and pyroxenes (En_{60}-En_{62}). The composition of the phases is similar to those of impact melts from other thin sections, thus this may be an impact melt. No xenoliths or xenocrysts are present, however. Thus, until further chemical analyses (bulk analyses) are done, identification cannot be made with certainty.

Clast 4 is a quickly cooled impact melt, which is about 50% glass and 50% crystallites of olivine (chain form) and plumose pyroxene. Pyroxene compositions from this clast overlap those of clast 3, but are generally more calcic and less magnesian.

CONCLUSIONS

The Apollo 15 glass-coated breccias studied are a series of complex breccias with some similarities and some differences. The glass rinds, summarized in the plot of Figure 3, are similar at the same site (i.e., 15255 and 15286), but differ from site to site. Comparison of the glass compositions with local soil compositions, where available, suggests strongly that the glass rinds originated by impact fusion of the local soil (see Winzer _et al._, in press, attached). The differences in texture and crystallinity between the rind glasses indicate somewhat different thermal histories, and possibly differences in ΔT between glass and breccia at the time of formation.

The breccias contain a significant number of exotic clasts, containing high iron pyroxenes and olivines, and high silica mesostasis glasses, with and without high potassium contents. The high potassium contents of the mesostasis glasses in some of these rocks suggests a high KREEP component, but confirmation of its presence will have to wait for lithophile trace element analyses.

The occurrence of ferroaugite and fayalitic olivine, previously suspected from fragmented material in the matrix of 15255, is now confirmed, but cristobalite was very rare. Siliceous glasses were much more common. Studies of the clasts found in the Apollo 15 breccias confirmed the suspected presence of basalts, but the occurrence of these iron-rich phases was not restricted to the mesostasis of the igneous clasts, as was hypothesized earlier (Nava _et al._, 1977).

The presence of ferrogabbros and basalts containing significant proportions of high iron phases is interesting, and hitherto unsuspected. Clasts returned from the soil of the Luna 24 landing site are similar (Barsukov, 1977; Florensky et al., 1977), thus establishing similarities between two widely separated sites.

Finally, it can be said with some certainty that all of the breccias included in this report have a significant soil component in their makeup. The presence of glass spheres, with compositions identical to the emerald green glasses found in the Apollo 15 soils (Reid et al., 1972; Agrell et al., 1973), and the presence of glass shards and droplets, signify the soil component in these breccias. These are not typical lunar soil breccias, however, in that they are tough and not friable, and they are bound together by a glassy matrix, which may be partly crystalline.

The full history of the formation of these breccias and their clasts will have to await further chemical, isotopic, and mineralogical studies.

TERRESTRIAL SAMPLES

THE ZHAMANSHIN STRUCTURE

Studies of samples obtained from the Zhamanshin structure have occupied most of the time spent on terrestrial impactites this year. The Zhamanshin structure is located about 200 km north of the city of Aral'sk, in Kazakhstan, SSR (Figure 10). It is a small crater, ~ 10 km in diameter, in a hilly semi-desert (Florensky, 1975). The impact involved crystalline rocks of paleozoic age as well as Cretaceous, Paleogene, and Neogene sandstones and limestones (Florensky, 1975, see Figure 10). Among the suite of impact melts and breccias, Florensky identified glasses of siliceous composition, which showed chemical homogeneity, as a new group of tektites to which he has given the name Irghizite. Samples of Irghizite glasses, impact melts (called Zhamanshinites), and breccias have been examined as part of a consortium effort involving several scientists in this country (Annell, DeGasperis, Ehmann, Fleisher, Fredriksson, Glass, Philpotts, Remo, and Winzer). This portion of the report summarizes the petrography and petrology of the tektites and impactites studied in this laboratory, in cooperation with personnel at Goddard Space Flight Center.

Several dozen individual droplets of glass were examined in hand specimen and with the binocular stereomicroscope prior to their splitting for thin sections and for allocation to the various members of the consortium. Among the specimens examined were Irghizites, Zhamanshinites, and breccias from various locations in the crater. The different groups of samples are described below.

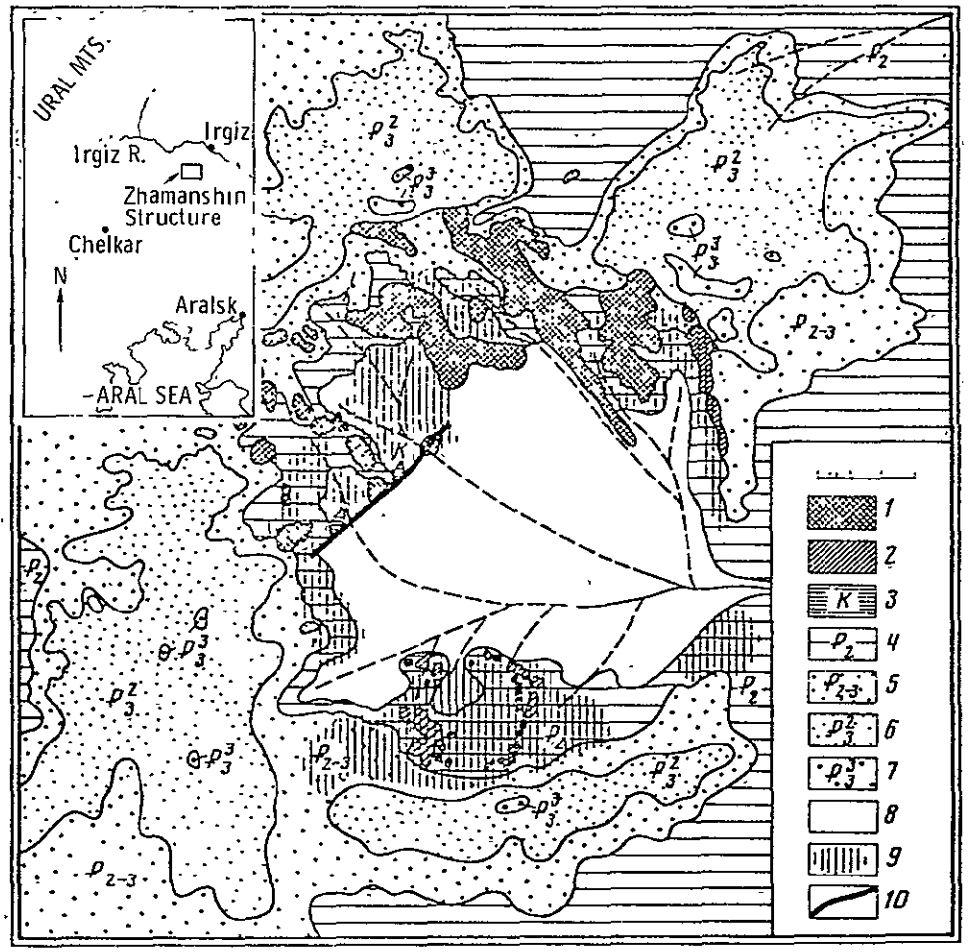

Figure 10. Geological map of the Zhamanshin structure, USSR. 1) Allogenic breccias, with lower and mid-Paleozoic rocks predominate; 2) Allogenic breccias containing upper Paleozoic rock fragments; 3) Cretaceous rocks; 4) Tasaransk and Saksaul series (Eocene); 5) Chegansk series - upper Eocene - lower Oligocene; 6) Chiliktinsk series - mid Oligocene; 7) Chagraksk series - upper Oligocene; 8) Quaternary loess; 9) Zhamanshinite and Irghizite locations; 10) Faults. Map after Florensky, 1975.

Irghizites

The original set of 26 Irghizite samples sent by Florensky were initially examined by Fredriksson (Fredriksson et al., 1977) prior to sectioning for analysis by electron microprobe. These samples were re-examined by me after sectioning and were analyzed in somewhat more detail using the SEM/Microprobe. Hand specimen and binocular microscopic examination of the tektite samples indicated two textural groups. One group, containing the most samples, comprised several forms with vitreous glassy exteriors, often with small, round bubblelike lumps of glass prominently displayed (Figure 11, left-hand side). These forms could be ropy, rounded, irregular, or dumbbell-shaped, and showed a few large voids or vesicles. The other, smaller group, included material with a duller, highly vesicular surface, which was pumicelike in appearance. Some of these had included angular fragments, usually milky white in color (see Figure 12, lower right-hand side). Fredriksson found two distinct chemical groups, one of which was siliceous (SiO_2 ~ 74%) and one of which was considerably more basic (SiO_2 ~ 54%). Upon re-examination of the samples, it was found that, in general, those in the glassy, less vesicular group that were identified on the basis of texture were siliceous; those in the vesicular, dull pumicelike group were basic.

Detailed examination of both groups of tektites was undertaken in this laboratory. Examination of thin sections of both siliceous and basic glasses included in the Irghizite samples were made, and further analyses were made with the SEM/EDS system. The siliceous Irghizites were found to be

Figure 11. Photomacrograph of siliceous tektite glasses from the Zhamanshin structure, USSR.

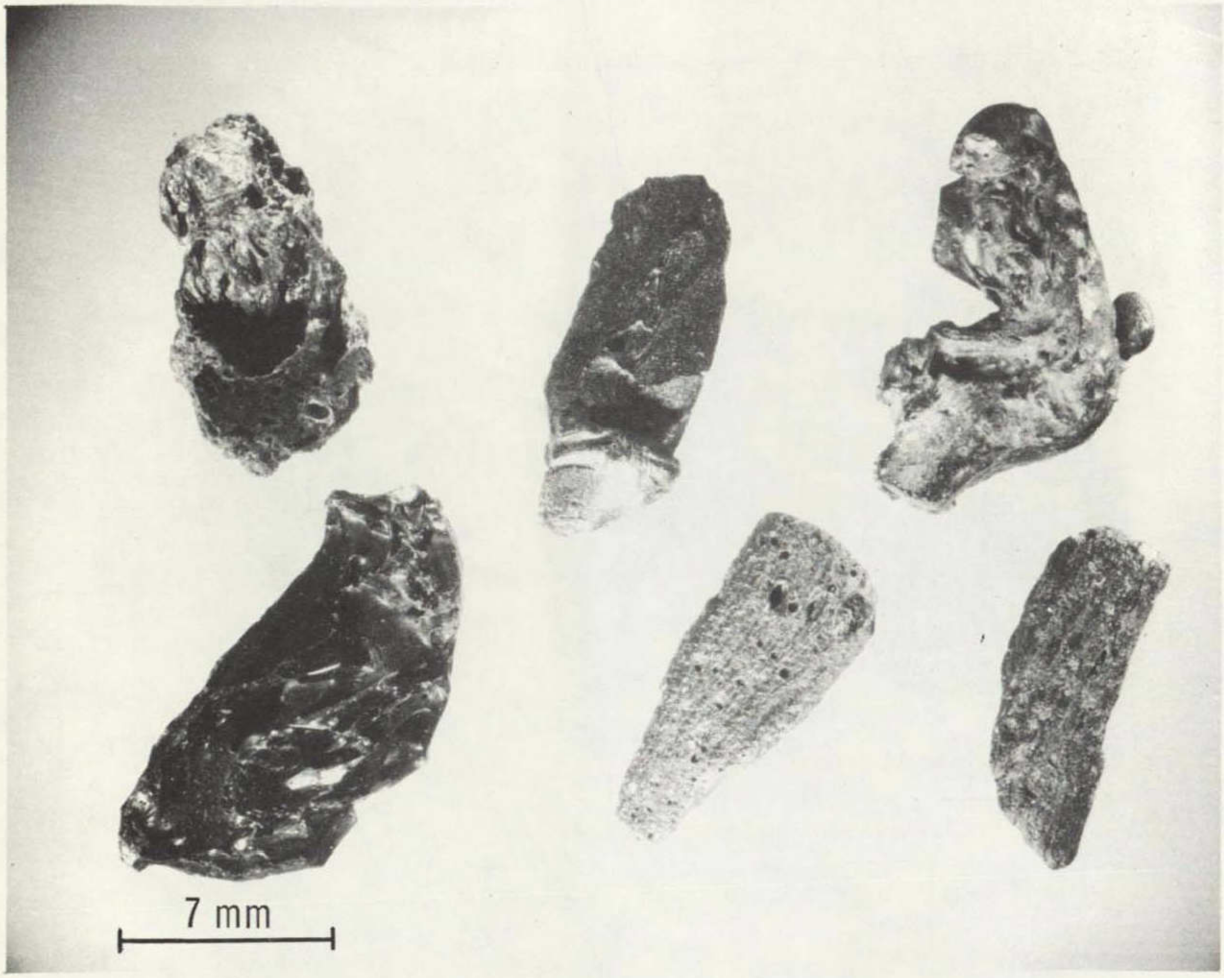

Figure 12. Photomacrograph of siliceous tektite glasses and basic glasses from the Zhamanshin structure, USSR. The two fragments in the lower right are basic glasses.

virtually fragment-free glasses with a few vesicles. Several of the glasses had textures that indicated formation by agglomeration of glass droplets while they were still sufficiently viscous to flow. These textures appeared as follows: Some slides contained glass areas separated from one another by thin "septa," identified as a brownish line dipping into the glass. These septa were often seen "radiating" from irregularly shaped vesicles that had the appearance of deformed voids occurring where two or more droplets came together. Other droplets, which could be seen in thin section as small spheres, and which corresponded to the small bubblelike lumps on the surface of the hand specimens, were found to be separated from the bulk of the glass by the same type of septa. Analyses of separate droplets indicated that all were identical in composition and were identical to the bulk glasses analyzed by Fredriksson.

One or two of the siliceous Irghizites contained vesicles that were filled with fragmental material (Figure 13). This material turns out to be fragments of quartz, feldspar, garnet, ilmenite, rutile, and glass, with a composition more basic than the siliceous Irghizite, but not identical to the basic Irghizite. The rim of the chondrule-like vesicle is enriched in MnO (up to 3% by weight of the oxide). A broad-beam analysis of the fragmental material showed that it is similar in SiO_2 and Al_2O_3, but different in alkalis and in FeO and MgO, from the siliceous Irghizite glass (see Table 2). The "chondrule" is about 400-µm in diameter, thus the sample size is highly restricted; however, the excellent agreement between several elements (SiO_2, TiO_2, Al_2O_3, and K_2O) are suggestive. The materials in the chondrule are terrestrial, and a likely hypothesis is that they were collected at the time the tektites formed. The assemblage is what one would expect from the soil, and the enrichment in manganese at the rim near the

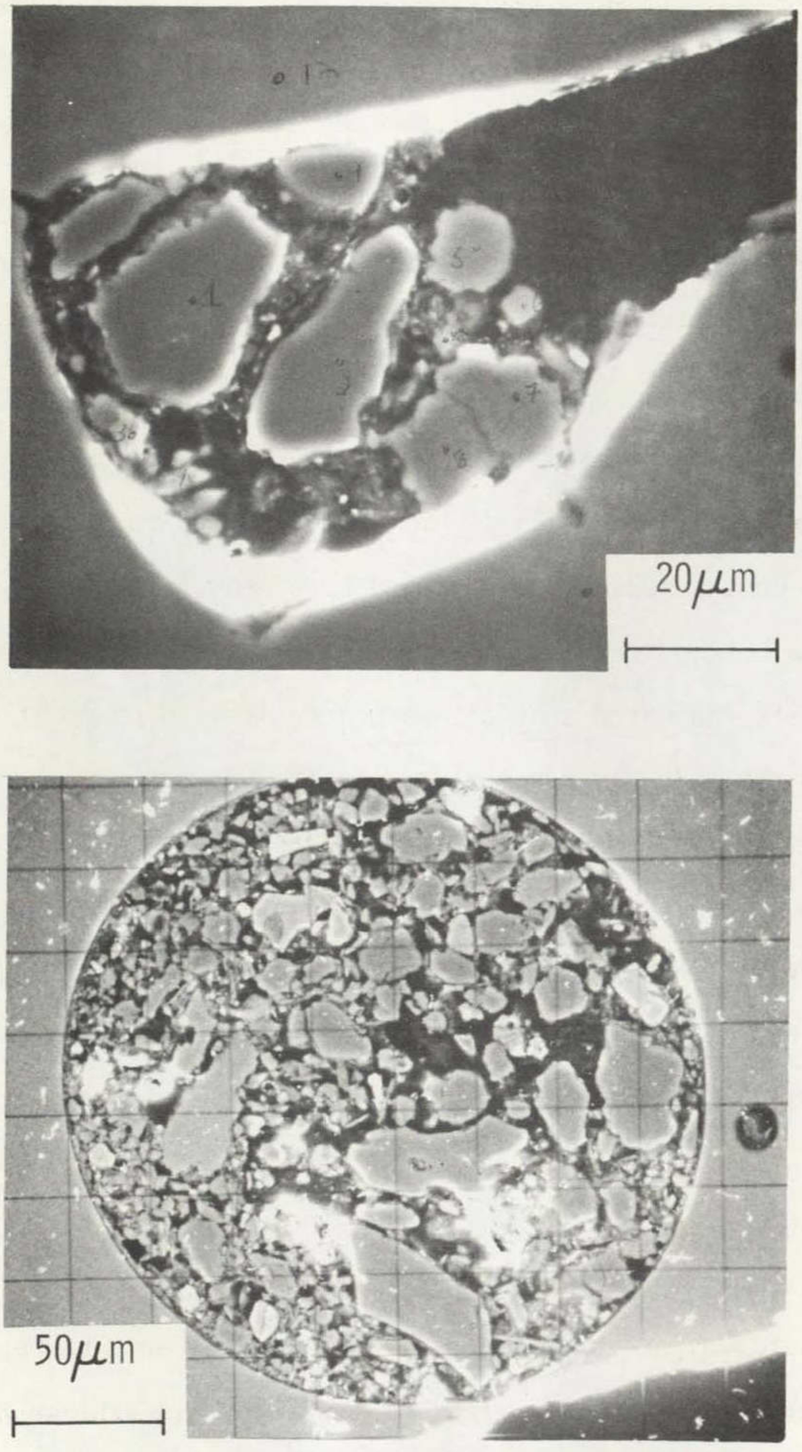

Figure 13. Scanning electron photomicrographs of vesicle and chondrule fillings in siliceous (Irghizite) glass. The granular material is principally quartz, with feldspar, garnet, rutile, ilmenite, and glass(?).

glass-fragment contact could be explained as incorporation of desert varnish into the still hot glass. Desert varnish, generally enriched in manganese, is to be expected in the semidesert region where the crater is located. It is a reasonable first hypothesis that the incorporated material is soil, and that the glass of the siliceous Irghizites themselves was formed by fusion of the soil. A further discussion of this hypothesis will be made at the end of this section.

Detailed examination of the basic glasses revealed a different paragenesis from the more siliceous material. The basic glasses were considerably more vesicular and did not show textures indicative of formation by coalescing droplets of glass. The basic glasses were extensively flowed, with bands of clear glass alternating with bands of dark glass containing crystallites of feldspar, and sometimes olivine. Fragments of quartz and feldspar, and even very small lithic fragments, were found. The glass in this material was heterogeneous, as opposed to the homogeneous siliceous glasses.

Figures 14 and 15 illustrate the composition and the range in composition for siliceous Irghizites and basic glass. In addition, the composition of other major tektite groups are plotted for comparison. The fundamental differences between siliceous and basic Irghizite glasses are clearly shown by these plots. The siliceous Irghizites overlap the compositional field defined by the Australasian tektites. The basic Irghizites do not match any other group of tektites. To explain these facts, it is necessary to look at the Zhamanshinites.

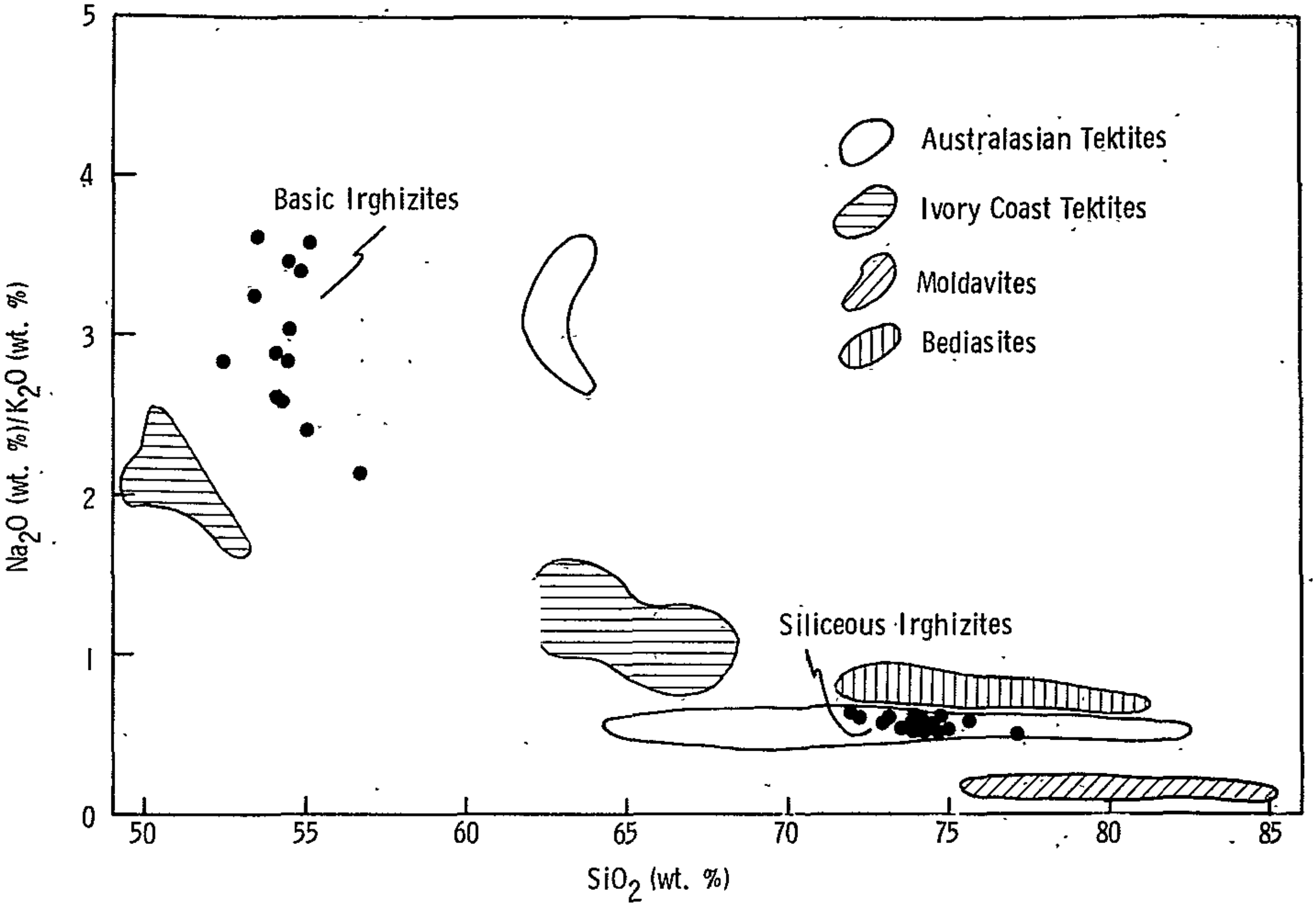

Figure 14. Plot of Na_2O (wt.%)/K_2O (wt.%) against SiO_2 (wt.%) for basic glasses, Irghizites, and other tektites.

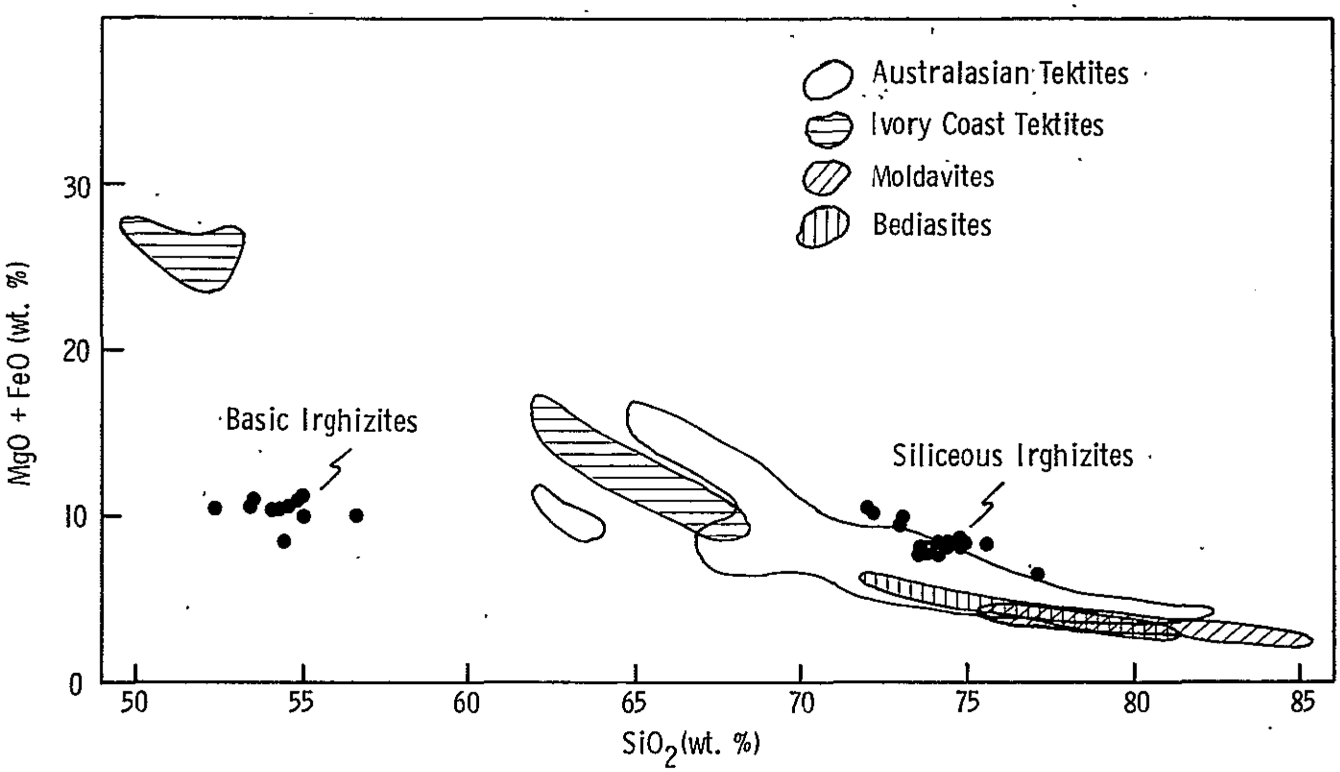

Figure 15. Plot of MgO + FeO (wt.%) against SiO_2 (wt.%) for basic glasses, Irghizites, and other tektites.

Impact Melts

The Zhamanshinites comprise a suite of impact melts and breccias that have a considerable range in composition and texture. Florensky (1975) described impact melts and shocked rocks from several locations in the Zhamanshin crater. These shocked rocks and impact melts (which he called slags, and to which he gave the name Zhamanshinite) can occur as small objects a few centimeters across, as 1-m blocks, and in rare cases, as "puddles" up to 10 x 5 x 5-m. The Zhamanshin structure does not appear to have an exposed melt sheet. Most the the material appears to be ejecta, and from the compositional changes within regions of the crater, appears to be produced by local melting of the bedrock in various regions of the crater.

The suite of impact melts and shocked rocks we received were not representative of all the types described by Florensky. Only a few samples of impact melt have been received, and only two samples of target rock. These rocks have been examined in detail in hand specimen and in thin section. The bulk of the samples are rapidly quenched impact melts consisting of glass and crystallites of feldspar, magnetite and minor olivine, and pyroxene. Figure 16 is a plot of glasses from all of the impact melts studied. These plots include vesicular siliceous fragment-laden impact melts that contain lechatelierite and a range of more basic melts with differing degrees of crystallinity and variable fragment contents. Basic and siliceous Irghizites are plotted for comparison.

On the plot of alkalies against Al_2O_3, the basic and siliceous Irghizite glasses define each end of a continuous series of glass compositions. On the plot of MgO + FeO against Al_2O_3, the basic Irghizites are included within the range of glass compositions from the impact melts. The siliceous

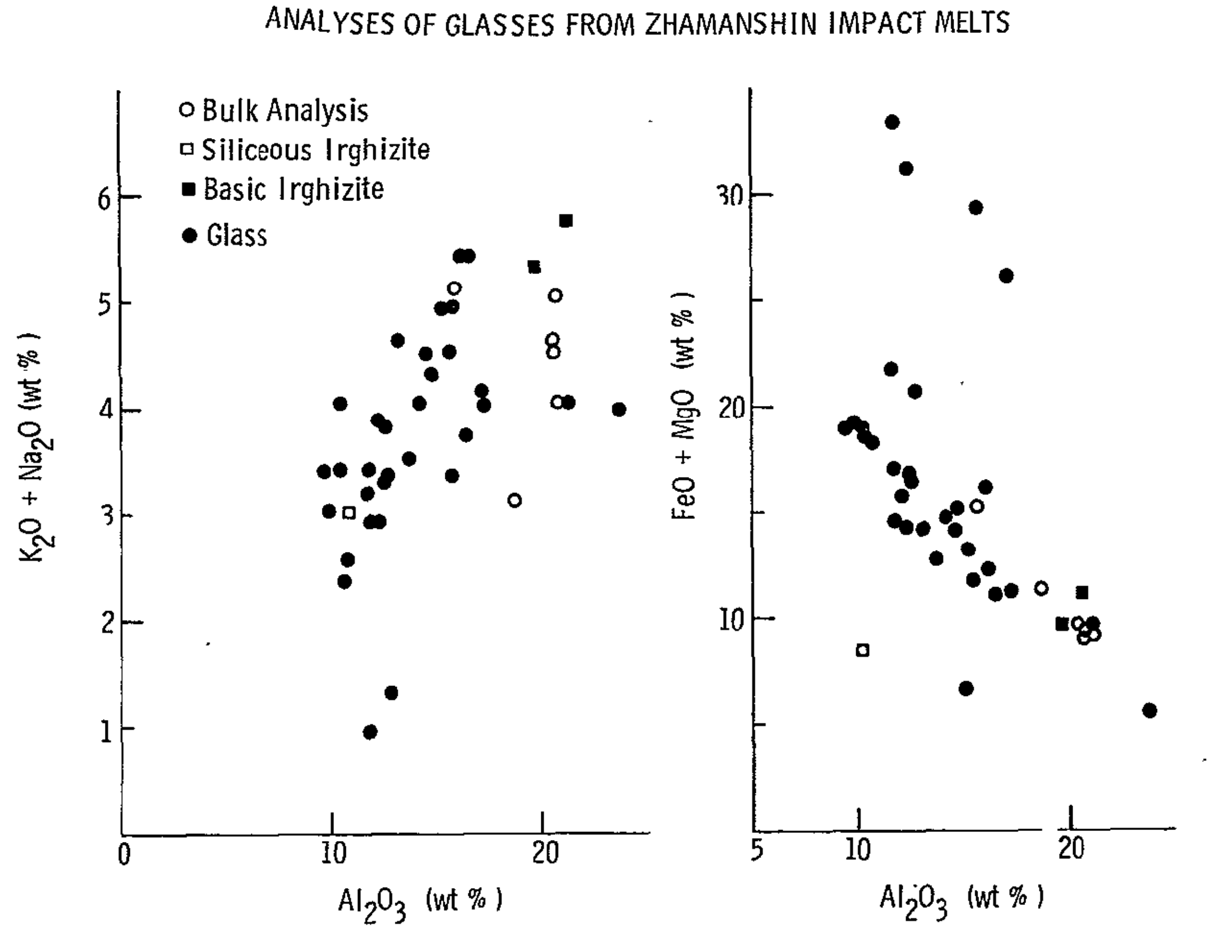

Figure 16. Plots of $K_2O + Na_2O$ and $FeO + MgO$ against Al_2O_3 for impact melts, basic glasses, and siliceous Irghizites from the Zhamanshin structure, USSR.

Irghizites lie off the trend of most of the other glasses, indicating their relative deficiency in MgO + FeO.

Figure 17 is a plot of plagioclase compositions and Niggli normative mineral compositions, calculated from glass and bulk analyses of the impact melts. The normative plagioclase shows good agreement with actual plagioclase compositions, supporting the hypothesis that these minerals crystallized in equilibrium with the melt during cooling. The normative pyroxene compositions show a wide scatter, and do not agree well with pyroxene that was actually crystallized. Few pyroxenes large enough to analyze were found, so it is not a good sample. Textural analysis indicated that pyroxenes crystallize after plagioclase and magnetite, which appear to crystallize together. Crystallization of magnetite would deplete the melt in iron; thus, the first pyroxenes to crystallize would be magnesian. This appears to be the case for the few pyroxenes present, and would probably lead to a much lower scatter, since the degree of iron enrichment indicated in the normative pyroxenes would be less in the pyroxenes that actually crystallize from the melt.

CONCLUSIONS

Firm conclusions on the origin of the tektites and the formation of impact melts from the Zhamanshin structure cannot be made at this time, because the number of representative samples is small. Some hypotheses can be advanced and tentative conclusions drawn, however. Among the first is that the basic glasses included with the Irghizites are impact melts and are a part of the Zhamanshinite suite. This conclusion is based on firm evidence, as the basic glasses are similar or identical to Zhamanshinite impact melts,

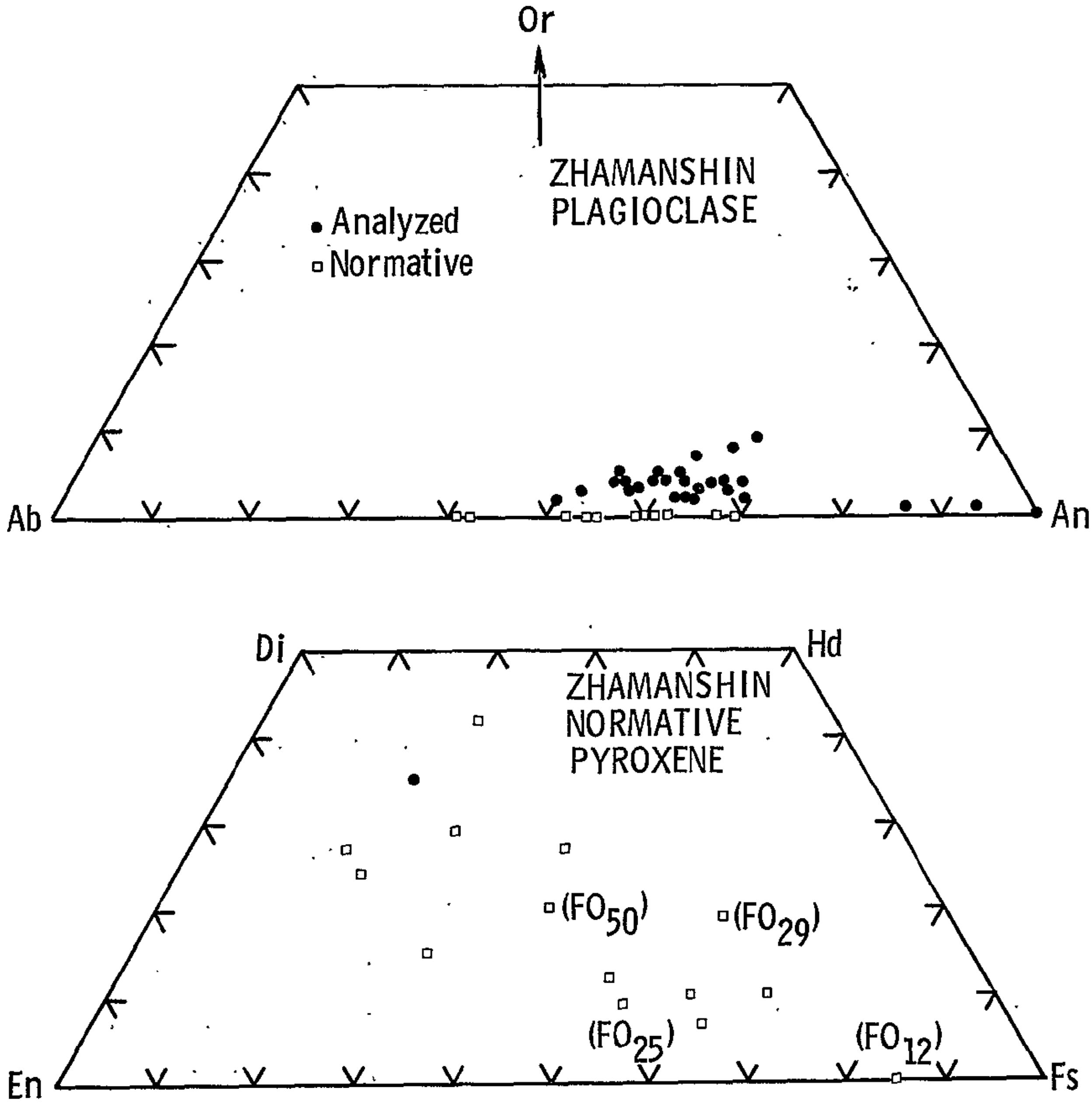

Figure 17. Plagioclase, pyroxene, and normative plagioclase and pyroxene compositions in impact melts from the Zhamanshin structure, USSR.

both chemically and texturally. The basic glasses have crystallized plagioclase, both as "coronas" around included mineral and lithic fragments and in regions (usually defined as flow lines or belts) in the glasses. The impact melts contain more fragments, and have crystallized more plagioclase, magnetite, and pyroxene than the basic glasses. This is likely due to the fact that the bodies of melt are larger and take longer to cool, thus leaving more time for crystallization.

The trace element content is the same for impact melts and basic Irghizite glass (Figure 18). This supports the hypothesis that the two are the same. Figure 18 shows the lithophile trace element content of two siliceous Irghizites, one basic Irghizite, one impact melt, and two country rocks (Philpotts et al., 1977). Comparison of the basic Irghizite and the impact melt indicates that they are identical.

Comparison of texture; mineralogy; and major, minor, and trace element chemistry, indicates that these two types of glass are the same, and that their formation is by impact fusion. Just what has actually been fused cannot be determined as yet. Examination of the trace element plot (Figure 18) indicates that neither of the two country rocks were the parent material, although they may have been components in a complex parent material. The target rocks at the Zhamanshin site are varied. Sediments, metamorphic basement complex, and volcanic and metavolcanic rocks are involved. We have not as yet obtained samples of these other rock types; thus, firm conclusions about the parent materials involved must await further sampling.

Figure 19 shows a comparison in the lithophile trace element abundances in other tektites and in the siliceous Irghizites. This plot indicates the similarity, already established by the major element plots, between

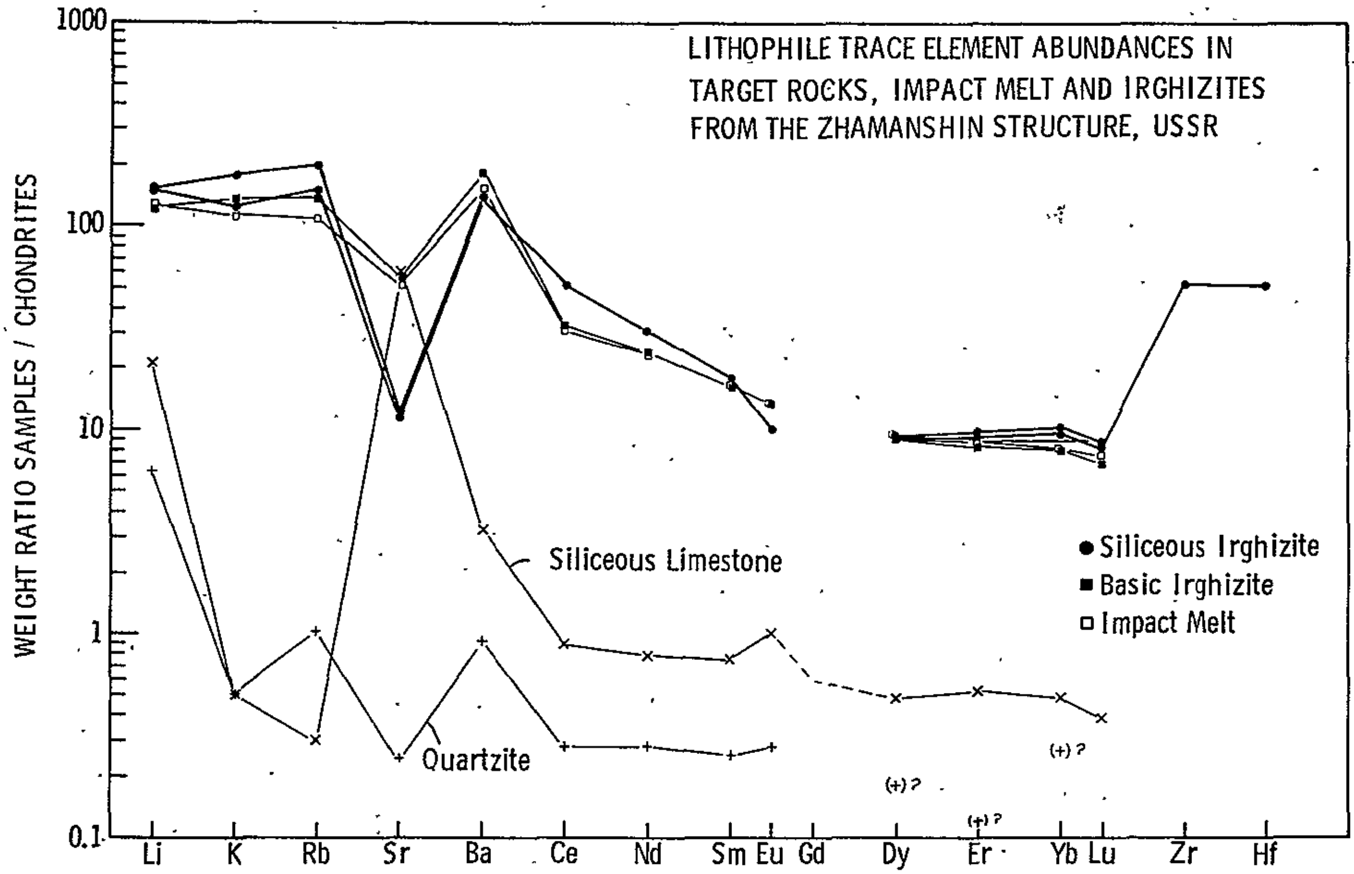

Figure 18. Lithophile trace element abundances in tektites, impact melts, and country rocks from the Zhamanshin structure, USSR.

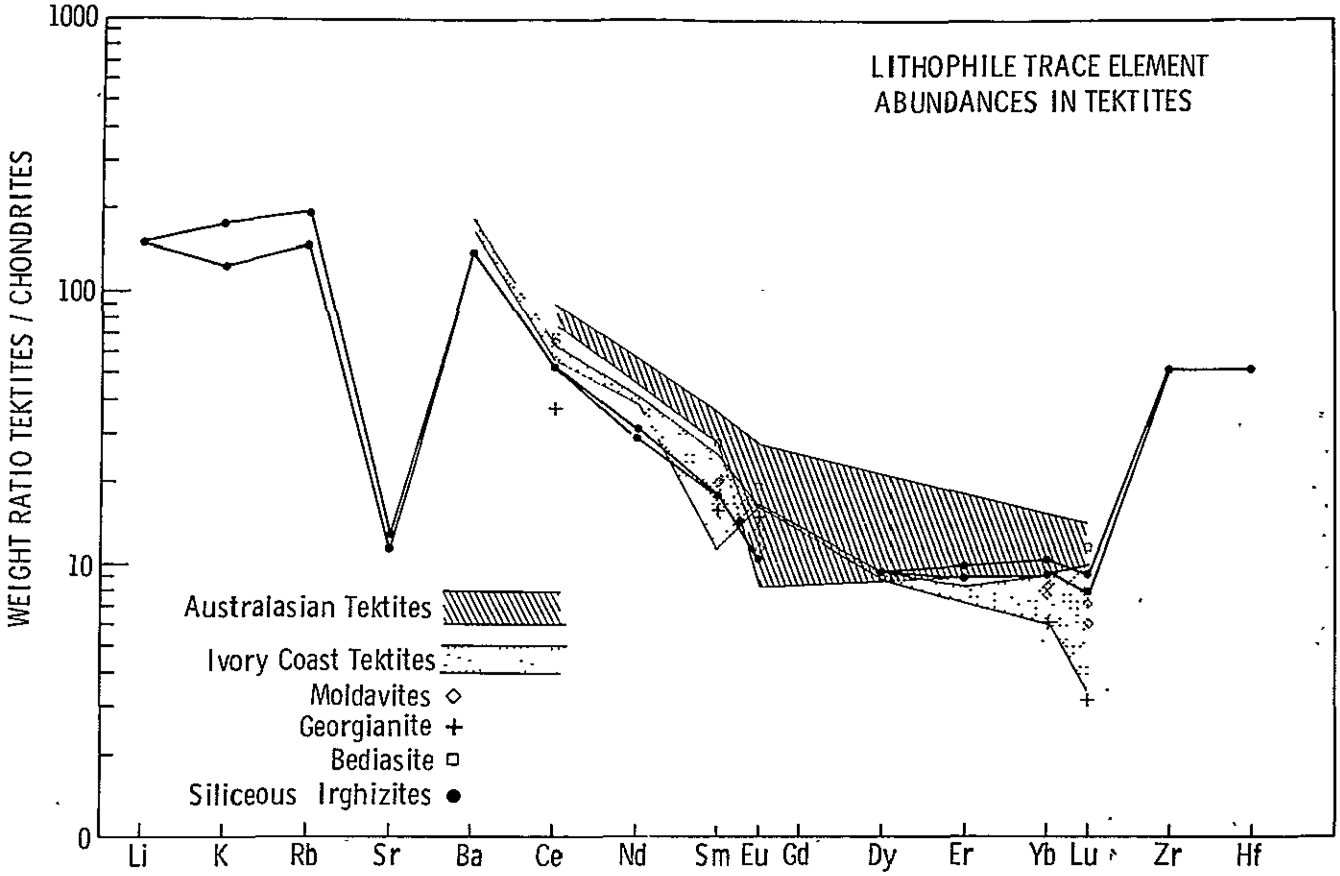

Figure 19. Lithophile trace element abundances in tektites.

Irghizites and other tektites, especially those of the Australasian strewn field. As indicated in the plots of glasses from impact melts, the siliceous Irghizites differ in MgO + FeO and in SiO_2 from most of the other impact glasses. They are, however, overlapped in some elements by some of the glasses, and appear similar or identical to bulk analyses of included fragmental material (Table 2). These similarities suggest the hypothesis that the siliceous Irghizites were formed by fusion of such fragmental material. The logical source for this material is the soil. Requests have been made for samples of the local soil, so that this hypothesis can be tested.

Finally, impact melting at the Zhamanshin structure appears to be a local phenomenon, as indicated by Florensky's (1975) description of the occurrence of impact melts and shocked rocks. The Zhamanshin structure does not appear to contain a melt sheet, as do some larger craters. Unraveling some of the puzzles posed by the appearance of tektite glasses, impact melts, and shocked rocks at the Zhamanshin structure should shed light on the modification of lunar surface rocks and soil by small impacts.

TABLE 2

Analyses of Chondrule Filling, Glass Rim, and Bulk Irghizite Glass (all wt.%)

	Area Analysis Chondrule Filling	Glass Rim	Bulk Glass*
SiO_2	75.64 ± 1.05	75.36	74.76
TiO_2	1.29 ± 0.23	1.16	0.87
Al_2O_3	12.79 ± 0.25	11.65	10.19
FeO	2.61 ± 0.18	3.55	5.68
MnO	0.22 ± 0.03	3.13	NA
MgO	0.83 ± 0.08	1.51	2.79
CaO	1.34 ± 0.05	0.84	~~2.52~~
Na_2O	2.11 ± 0.26	0.58	1.12
K_2O	2.05 ± 0.10	1.49	1.83

* Analysis by Fredriksson using wavelength dispersive spectrometry.

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ATTACHMENT

A STUDY OF GLASS COATINGS FROM SOME APOLLO 15 BRECCIAS; S.R. Winzer, K. Brean, A. Ritter, M. Meyerhoff, and P.J. Schuhmann, Martin Marietta Laboratories, 1450 South Rolling Road, Baltimore, Maryland.

Several glass-coated breccias from the Apollo 15 landing site are being studied in order to determine the origin of the coatings and the relationship of the coating to the breccia. The glass-coated samples under study are 15255, 15286, 15465, 15466, and 15505. 15255 and 15286 were collected at Station 6, the easternmost point on the Apennine Front. 15255 was the on the surface 25 m from a 12-m diameter crater, and 15286 was on the inner bench of this crater. 15465 and 15466 were collected from the rim of Spur Crater (Station 7), and 15505 is a sample from the ejecta blanket of a 15-m diameter crater at Station 9.

Petrography

The glass coatings on all the breccias studied are grossly similar, but differ significantly in detail. The principal differences include vesicularity, continuity (across the breccia surface), chemical homogeneity, degree of crystallization, and amount of included mineral fragments and clasts. All glasses are vesicular; however, the size and shape of the vesicles vary. In 15255, as noted by Nava et al. 1977(1), the glass rind in separated from the breccia by a thin layer of small vesicles. 15466, on the other hand, has no such layer. 15505,80 has a discontinuous, thin vesicular region separating the rind from the host breccia, and 15286, where the contact is visible, is similar to 15255. The degree of vesiculation is also variable from sample to sample, and sometimes within samples. 15466 contains the least number of open vesicles, 15255 the most. In all samples except 15286, the vesicles are close to circular in cross section; however, in 15286, the vesicles are deformed and, in some cases, appear to be coalescing to form irregular voids.

All glasses show an indication of flowage, with small color or refractive index differences defining flowage lines. All glasses contain mineral fragments, the most common being anhedral plagioclase ($An_{81} \rightarrow An_{100}$), with pyroxene and olivine, in that order of importance. Clinopyroxene is more common that orthopyroxene. Droplets of metallic iron are found in all of the rind glasses, while more complex droplets consisting of metallic iron and a sulfide are found in 15286 and 15466. The proportion of mineral fragments varies within each individual rind coating, as well as between samples. The most fragment-free glass is 15255, while 15286 and 15466 contain the highest proportion of fragments. These two glass coatings also contain large lithic clasts (breccias). These clasts, up to 0.5 mm in diameter, are similar to the host breccia, but cannot be conclusively established as part of it. In several cases, small fragments of the host can be seen breaking off into the glass rind, but the larger fragments are completely separated from the breccia host in the plane of the thin section.

Two of the glass coatings show some degree of devitrification or crystallization. 15466 exhibits small rims or coronas around included, anhedral feldspar grains. Larger breccia clasts included in the glass do not show coronas. 15286 is a special case among the five samples, in that the glass is the most chemically heterogeneous (see Table 1). Another section from 15286 was described by Wosinski et al. 1972(2), as a vesicular greenish-brown glass with some devitrification in the rind portion, especially near the glass-breccia boundary. We found that phases crystallizing from the glass appear as small crystallites (~ 5 µm) arranged in dendritic patterns, or as elongated crystals (80 µm) of chain or hopper form olivine (FO_{78-83}). The dendritic forms are also olivine, with somewhat higher fayalite content (FO_{76-78}) than the chain or hopper type. No pyroxenes are found in any of the devitrified areas, thus the presence of augite suggested by Wosinski et al. 1972(2) is not confirmed. In addition to included fragments and phases which have crystallized from the melt itself, droplets of Fe (Ni) metal with complex intergrowths of a sulfide mineral also occur in 15286. They are found in glassy areas free of crystallites as well as in areas where crystallization has occurred in our section. These droplets were noted by Wosinski et al. 1972(2), but they found no devitrification associated with them in their section.

15286 differs from 15466 in that phases have crystallized in fragment-free and clast-free areas as well as around included mineral and breccia fragments. We interpret this to mean that the glass from 15286 cooled slowly enough to nucleate and crystallize olivine, and was then quenched.

Conclusions

Studies of the five glass-coated lunar samples indicate that the glass coatings come from more than one source and were likely formed and cooled in different thermal environments. Preliminary studies of ~~15255 indicated~~ that the major ~~element composition of the glass~~ is similar to that of the ~~breccia~~; however, the trace element compositions are different(1). Wosinski et al. 1972(2) concluded, on the basis of comparison of the EDS spectra, that the rind and breccia of 15286 were similar in composition; however, the spectral comparison method is not quantitative, thus this conclusion must be taken with some reservation.

Comparison of the repeated quantitative analyses of the five glass rinds indicates that they differ significantly from one another, although the more heterogeneous glasses overlap one another in the concentrations of some elements (Table 1). The glasses do not appear, on textural grounds, to be melted examples of the host; rather, they appear to have encountered the host when the two were at significantly different temperatures, producing out-gassing in some specimens (like 15255, the vesicular contact area) and crystallization in others (15466 and 15286). It is a reasonable first hypothesis that the source for the glass rind is not the breccia itself, although components of that source could be present in both breccia and rind glass. Another reasonable hypothesis is that the source of the glass might be the local soil, which was fused and then splashed on the pre-existing breccia. To test this hypothesis, soil analyses from the Apollo 15 site were compared to the average glass analyses. Soil from Station 6 (15251,48) is identical (within analytical error) to 15286, and soils from Station 2 and Station 9 are closely similar for most elements, thus lending support to the soil fusion hypothesis (Table 1). There are some differences between glass coatings and some of the local soils; for example, SiO_2, FeO, and TiO_2 contents of the Station 9A soil 15601,45 and 15505,80, and the differences between 15255 glasses and Station 6 soil 15251,48 (see Table 1). Those differences may mean that the glass rinds for some of the breccias were not formed from local soil, but soil from another area or a mixture, or they may be induced errors, due to sampling or soil heterogeneity, which are not reflected in the few analyses presently available.

TABLE 1

	APOLLO 15 RIND GLASSES											APOLLO 15 SOILS		
	15466,22(7)*		15505,80(9)		15286,33(6)		15255,38(6)		15255,77(6)		15255,77	15101,67	15251,48	15601,45
	$\bar{X}$(21)**	1σ	$\bar{X}$(13)	1σ	$\bar{X}$(20)	1σ	$\bar{X}$(20)	1σ	$\bar{X}$(10)	1σ	WDS	Sta. 2	Sta. 6	Sta. 9A
SiO_2	45.98	±.39	49.65	±.65	47.35	±1.45	46.76	±.71	48.00	±.96	46.4 ±.50	45.97	47.02	46.44
TiO_2	1.42	±.10	1.72	±.14	1.44	±.14	1.74	±.15	1.61	±.23	1.8 ±.04	1.26	1.49	1.57
Al_2O_3	17.15	±.23	11.63	±.17	15.86	±1.62	13.91	±.79	14.37	±.44	14.1 ±.24	17.58	16.28	10.77
FeO	11.41	±.20	14.99	±.53	12.76	±1.29	14.58	±.53	13.24	±.45	14.7 ±.30	11.54	12.00	19.30
MnO	----		----		----		----		0.20	±.16	0.22 ±.02	0.157		
MgO	11.51	±.20	11.22	±.26	10.42	±2.46	11.29	±.32	11.43	±.41	11.1 ±.24	10.32	10.31	11.28
Cr_2O_3	0.36	±.08	0.49	±.17	0.45	±.14	0.46	±.12	0.44	±.02		0.33	0.30	
CaO	11.12	±.21	9.63	±.28	10.78	±.83	11.06	±.30	10.26	±.25	10.7 ±.20	11.71	11.25	9.37
Na_2O	0.76	±.27	0.45	±.46	0.45	±.51	0.18	±.25	0.77	±.40	(0.38 ±.02)	0.37	0.54	0.38
K_2O	0.16	±.07	0.21	±.07	0.21	±.07	0.16	±.08	0.10	±.09	(0.16 ±.02)	0.165	0.22	0.11

Apollo 15 rind glasses analyzed by SEM/EDS. Analyses are ±3% relative or better for concentrations above 2% (as the oxide), higher errors (to ± 10% relative) are encountered for concentrations below 2% (as the oxide), depending on the element. 15255,77 WDS from Nava et al. 1977(1), for comparison. Iron in the wavelength dispersive analysis is high due to the presence of Fe metal droplets. 15101,67 from Willis et al. 1972(3), 15251,48 from Cuttita et al. 1973(4), 15601,45 from Wanke et al. 1972(5).

* Number in parentheses is the station number.

**$\bar{X}$ is the mean, the number in parentheses is the number of analyses.

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