GARNETS IN MONTANA DIATREMES: A KEY TO PROSPECTING FOR KIMBERLITES

by

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Abstract

Garnet is a useful tracer mineral for kimberlite prospecting and garnet color can specifically indicate the presence of typical inclusions of upper mantle material. The most distinctive indicators are Mg-Cr-rich purple garnets, predominantly derived from upper mantle peridotites. Garnets in peridotite, in other inclusions and in colluvial deposits from the Williams kimberlites and other north-central Montana diatremes have been classified by color and analyzed by electron microprobe. Fifteen peridotites from the Williams diatremes contain purple garnets (Cr_2O_3 4.2 to 7.8 wt percent) and four contain red or red-orange garnets (Cr_2O_3 0.7 to 3.0). Twenty of 21 purple colluvial garnets are Cr-rich (Cr_2O_3 2.4 to 9.9) and the Cr-rich purple red and pink colluvial garnets are compositionally analogous to the peridotite garnets. Other colluvial garnets of pink, red, red-orange, orange and light orange color may have been derived from upper mantle inclusions but are not distinctively different in color compared to garnets from lower or upper crustal rocks. Those five color groups have bimodal Fe/Mg distribution, probably due to bulk compositional differences between the lower crust and upper mantle. Garnets of Mg/(Mg + Fe) greater than 0.67 contain more Cr than most of the Fe-rich garnets, indicating derivation of the Mg-rich group from upper mantle rocks or megacrysts. Many of the Fe-rich garnets are similar in composition to those of lower crustal granulites. One of six megacrysts is Fe-rich; five megacrysts are Mg-rich with Cr_2O_3 contents (0.6-2.3) less than most peridotite garnets.

Peridotite garnets show increasing Cr_2O_3 with increasing CaO in a trend which fits garnets coexisting with a two-pyroxene assemblage (lherzolite) from localities elsewhere in the world. In that trend, Williams peridotites tend to show a gap between bimodal distributions of Cr_2O_3 and CaO, but that gap is filled by some colluvial garnets that probably represent peridotites not yet found as xenoliths. Neither Cr-Ca-rich green garnets nor Cr-rich, Ca-poor garnets have been found.

Big Slide diatreme contains garnets similar to those in granulites present in the diatreme, and contains purple Mg-Cr-rich garnets of probable upper mantle origin. Limited sampling shows that Bullwhacker Coulee diatreme contains garnets similar to those in granulites and pyroxenites present as inclusions, but has found no Cr-rich purple garnets. Garnets from shallow Precambrian rocks have various colors (purple, pink and orange) and form a small cluster of Fe-rich, Ca-poor, Cr-poor compositions.

Introduction

Kimberlites typically contain some or all of the tracer minerals pyropic garnet, chromian diopside, enstatite, and magnesian ilmenite (Dawson, 1980). Examination of heavy mineral concentrates from alluvial and colluvial deposits and soils is a well-known technique for prospecting for kimberlites over the world. Heavy mineral concentrates are obtained by hand-panning, sluice-box or rocker-box concentrating, or by heavy-liquid or hydraulic techniques in the laboratory. Garnet is particularly suitable as a tracer because it is present in most kimberlites, is more abundant than other tracer minerals in many kimberlites (Dawson and Stephens, 1975), and is resistant to attrition during transport in comparison to other common tracer minerals (Leighton and McCallum, 1979).

Garnet in kimberlite is most commonly derived from disaggregated upper mantle material. Garnet in kimberlite can also be derived from lower or upper crustal rocks, or from shallow Precambrian rocks. In addition, garnets can be derived from shallow sedimentary rocks or from surficial deposits, which were disaggregated and incorporated into the kimberlite during its eruption. Garnets from any of these sources could be distinctive indicators of kimberlite in a drainage basin where other garnet-bearing source rocks are not exposed. Although many sources can contribute garnet to kimberlite, or to diatremes of other magma types, the garnets that are derived from deep upper mantle sources are distinctive indicators of kimberlite. Kimberlitic garnets of ultimate upper mantle origin can be derived from garnet peridotite, garnet pyroxenite, eclogite, or from megacryst assemblages. Megacryst assemblages in kimberlite are coarse-grained garnet, orthopyroxene, clinopyroxene, olivine, and ilmenite that are presumed to coexist at upper mantle temperatures and pressures. Megacrysts commonly occur as monomineralic inclusions, rarely occur as intergrown bimineralic inclusions, and very rarely occur as multimineralic inclusions. The large size of garnet megacrysts (>1 cm) is an obvious clue to the presence of kimberlite if large garnets are absent in surrounding bedrock. Garnet megacrysts, garnets from most garnet peridotites and garnets from many garnet pyroxenites are distinctly rich in chromium and thus are indicative of deep-source material in the kimberlite and of attendant potential for diamond. One type of garnet that is low in calcium and is particularly rich in chromium is found as inclusions in diamond (Meyer and Boyd, 1972) and as a component of diamond-bearing harzburgites and dunites (Finnerty and Boyd, 1980), but is extremely rare in kimberlite (Gurney and Switzer, 1973).

Two studies (Dawson and Stephens, 1975, 1976; Danchin and Wyatt, 1979) classify kimberlite garnets and xenolith garnets into cluster groups (12 and 52 groups respectively) on the basis of chemical composition. Their garnet populations include separate xenocrysts and megacrysts, garnets from lherzolite, harzburgite, dunite, pyroxenite and eclogite xenoliths, and garnet inclusions in diamond. Dawson and Stephens (1975, 1976) give limited color data for each group. Both studies exclude garnets from granulites, garnet amphibolites or other crustal rocks, as a result of scarcity of such xenoliths in African kimberlites or lack of distinctive criteria for xenocrysts of crustal origin.

During field or laboratory examination of heavy-mineral suites, color of garnet can be easily and rapidly determined and is a useful criterion of the presence of upper mantle garnets. Garnets from peridotites are dominantly purple, reddish purple, or deep red, and all have a moderate to high chromium content, typically 2.5 to 12 wt percent Cr_2O_3. Garnets from pyroxenites are purple, red or orange, and have low to moderate chromium content. Garnets from eclogites are typically red to light orange and have low chromium content. Megacryst garnets are generally red to red-orange; some are purple or light orange. A substantial proportion of purple garnets in a kimberlite indicates that garnet peridotite inclusions may be present. Substantial proportions of red, orange or light-orange garnets could indicate the presence of eclogites, in the absence of xenoliths of more shallow derivation such as granulite or amphibolite, which can contain garnets of those colors.

The purplish or deep red color of peridotite garnets is distinctive and can be recognized in the field during hand lens study of garnets in soil, in surficial deposits, in pan concentrates, or in the actual kimberlite. Recognition of these garnets is enhanced by their tendency to occur as clear unfractured grains or as grains with clean, glassy conchoidal fracture surfaces. Determination of color can be improved by viewing in direct sunlight and by wetting the grains. For grains that are partially coated by kelyphitic reaction rims or that are imbedded in kimberlite matrix, determination of color can be aided by focussing a bright spot of sunlight onto the grain with a hand lens.

Techniques of color classification

The classification of garnets into color groups was done megascopically using a binocular microscope with an American Optical incandescent, unfiltered light source to simulate techniques which could easily be used in the field; however, such classification is subjective. Variables affecting color determination are the light source, size of grains, background color, color of adjacent grains, surface irregularities, presence of tiny inclusions or fractures, and perceptual idiosyncrasies of the observer. It is important to compare many grains in the same field of view because some color groups might not be represented in a small sample, and the divisions between the groups are usually arbitrary because of complete gradation between some color groups. Surficial abrasion makes grains appear lighter in color. Internal fractures can have the effect of decreasing the visible volume of a grain and thus lightening the color. Garnets that are surrounded by dark pyroxenes or serpentinized olivine in an inclusion can appear to have different color than they would show as single loose grains, so for the best comparison the garnets should be picked out of inclusions or matrix. Classification was aided by using white paper underneath the grains to provide a uniform background and make the colors more distinctive. Garnets should be approximately the same size, as smaller grains or thin flakes appear lighter than larger grains. The observer can compensate for some of these variables, for example by placing light-purple, purple, and dark-purple grains in the same color group.

It is likely that in classifying the same garnet sample, two observers will have slightly different numbers of grains in each color group. This difference will be of little importance if the number of garnets is large enough to give a good statistical base, and if the color groups are regarded as gradational. Color groups may be chemically gradational as well. For example, some red grains are chemically similar to some purple grains, and some color groups may show extensive overlap in their chemical compositions.

Summary of Samples

This study has concentrated on garnets of the Williams kimberlite diatremes. Smaller samples of garnets from other diatremes and bedrock and detrital sources have also been analyzed. Locations of the diatremes are given in Hearn (1979) and in the tables.

Garnets have been classified by color and analyzed by using an automated ARL-EMX electron microprobe with on-line data reduction using the Bence-Albee (1968) method. Silicate standards were used for all elements except Cr, for which a synthetic Cr_2O_3 standard was used. A natural pyrope garnet from Kakanui, New Zealand was always analyzed as a check on the standardization.

Analyzed garnets from the Williams diatremes area are from several types of samples: panned concentrates from colluvium adjacent to the Williams 4 diatreme, and from a colluvial lag deposit on the Williams 1 diatreme (table 1); inclusions of fresh and altered garnet peridotite (tables 2 and 3); megacrysts (table 4); and inclusions of granulite and amphibolite (table 5). Garnets in various samples from other diatremes (panned concentrates, granulite, gneiss, and schist inclusions, and xenocrysts), in Precambrian bedrock, and in detrital deposits from presumed Little Rocky Mountains sources (table 6) were classified by color and analyzed for comparison to garnets from the Williams diatremes. Published analyses (Hearn and Boyd, 1975) and unpublished analyses (by F. R. Boyd and by the authors), of garnet megacrysts and garnets from peridotite inclusions in Williams diatremes are also given (tables 2, 3, 4 and 5).

Geology of the Williams Diatremes

The Williams kimberlites are a group of four closely spaced diatremes (fig. 1) in the eastern part of an east-northeast trending swarm of ultramafic alkalic diatremes, dikes, and plugs of 46-51 million years (middle Eocene) age (Marvin and others, 1980) in the Missouri River Breaks area of north-central Montana (Hearn, 1968, 1979). The western end of the swarm is represented by the Haystack Butte intrusion (Buie, 1941) on the eastern flank of the Highwood Mountains, and the easternmost occurrence is the Ricker Butte group of intrusions, on the southeast flank of the Little Rocky Mountains. The diatremes and intrusions were produced by alkalic ultramafic magmas that crystallized to alnoite or monticellite peridotite. Their fine-grained fresh equivalents, which would correspond to olivine nephelinite or olivine melilitite, are typically altered to secondary assemblages in bedded pyroclastic deposits within the diatremes. Such alkalic ultramafic magmas occur in the same broad geographic areas as kimberlites in other parts of the world (Dawson, 1980), and are likely to have been parental to many kimberlites. Although the alkalic ultramafic character of the Missouri Breaks diatremes indicates kimberlitic affinity, only the Williams diatremes can be termed true kimberlite on the basis of the presence of the typical kimberlite indicator minerals chromian pyrope, chromian diopside, enstatite, and magnesian ilmenite (Dawson, 1980).

Two of the Williams diatremes are major pipes and two are smaller, satellitic pipes. Williams 1 is very poorly exposed and was mapped by soil types, presence of indicator minerals in soils and in animal burrows, and limited soil-auger sampling. Williams 1 is a diatreme of rounded triangular shape, about 250 by 350 m in size, which has been emplaced against the ring fracture of the Siparyann Butte (Thornhill Butte) dome, a dome of Cretaceous to Cambrian sedimentary rocks that were uplifted at about 61 m.y. above a hornblende syenite porphyry intrusion (Brockunier, 1936; Knechtel, 1959; Marvin and others, 1980). Wall rock of the west, south and north sides of the kimberlite is dominantly shale, with minor beds of limestone and sandstone, of the Colorado Group of upper Cretaceous age. Wall rock to the east is Paleozoic limestone, dolomite, and calcareous shale in the dome. The diatreme mainly contains soft, clay-rich kimberlite breccia, rich in inclusions of Cretaceous and early Eocene sedimentary rocks. A small intrusion of partially altered monticellite peridotite or massive kimberlite is present in the southern part. Downfaulted blocks of sandstone and claystone of Wasatch Formation (early Eocene) probably about five to a few tens of meters in size, occur on the border of the Williams 1 diatreme, similar to other Missouri Breaks diatremes that contain large slices of sedimentary rocks that have subsided as much as 1500 m from the Wasatch and older formations. Blocks of Cretaceous shale and sandstone one to several meters in size are also present. The presence of olive-green pyroxenes of slightly rounded, prismatic euhedral shape in panned concentrates, and presence of rare pebbles of phonolite, indicate that the diatreme also incorporated detrital material derived from the Bearpaw Mountains volcanic fields in middle Eocene time (Hearn, 1979).

The poorly exposed Williams 2 pipe, about 40 by 120 m, contains kimberlite breccia that is rich in limestone and dolomite fragments from the surrounding Paleozoic rocks. Williams 3, about 30 by 40 m, primarily consists of one or more blocks of sandstone and siltstone that have subsided a few hundred meters from the Eagle Sandstone or from the Telegraph Creek Formation, and occupy the whole pipe area except for a small marginal occurrence of kimberlite breccia.

Williams 4 is a dike-like diatreme 390 m long and up to about 40 m wide. Parts of Williams 4 are well exposed. The dike is variable in texture along strike. Massive kimberlite forms several areas from two to a few tens of meters across; the rest of the dike has fragmental texture or is unexposed. Some massive outcrops show cryptic fragmental texture on close examination. A portion of the dike near its southwestern end contains abundant autoliths 0.5 to 8 cm in diameter. Most autoliths contain cores of baked shale, baked sandstone, or igneous rock (kimberlite or monticellite peridotite?) of slightly coarser texture than the peripheral micaceous igneous coating.

Inclusions from deep levels -- Ascended inclusions are from the Precambrian basement (2000 m and deeper), the upper crust (schist, gneiss, amphibolite), the lower crust (granulite, mafic granulite, mafic amphibolite), and the upper mantle (spinel peridotite, dunite, garnet peridotite, garnet megacrysts, xenocrysts of kimberlite indicator minerals). Neither eclogites nor diamonds have been found. Assignment of lithologies to the upper or lower crust is tentative and based on analogies with inclusion suites in diatremes elsewhere, and on sequences of metamorphic textures and facies elsewhere. Garnets occur in rocks from each of the above listed depth zones. Study of the entire suite of inclusions is in progress, but so far has mainly concentrated on the upper-mantle garnet peridotites. In addition, six megacryst garnets, and garnets from three mafic granulites, two mafic amphibolites and two inclusions of unknown depth of origin have been analyzed.

Garnets from garnet peridotites -- Sheared (porphyroclastic and mosaic-porphyroclastic, Harte, 1977), and granular (coarse, Harte, 1977) peridotites are present but are rather rare in Williams 1 and 4 diatremes. Some granular-textured peridotites show necklace texture of thin zones of fine-grained recrystallized olivine surrounding large olivine crystals. Because of alteration, the texture cannot be determined in many peridotites. In altered peridotites, serpentinization and weathering have produced pseudomorphs of all of the primary olivine and enstatite, but garnet, and less commonly diopside, survive. All eight fresh peridotites contain lherzolitic assemblages (olivine + clinopyroxene + orthopyroxene) but some contain less than one percent clinopyroxene. Garnets from eight fresh peridotites and from eleven altered peridotites have been analyzed (tables 2 and 3). These garnets are typically unzoned, and are the same composition, or show a small range in composition, within each peridotite xenolith. All the garnets are pyrope rich and have Mg/(Mg + Fe) of more than 0.78 (fig. 3). Garnets from 15 of the 19 peridotites contain more than 4.0 wt percent Cr_2O_3, and the maximum is 7.83 percent; garnets from the remaining four contain 0.7 to 3.0 wt percent Cr_2O_3. Garnets from one sheared peridotite contain the lowest amount of Cr_2O_3 (coarse-and fine-grained garnets are slightly different in composition) and garnets from the other two sheared peridotites plot with the higher Cr_2O_3 group of garnets (figs. 3, 4 and 5). All 19 of the analyzed garnets (from 15 peridotites) with more than 4.0 wt percent Cr_2O_3 are purple in color; the six analyzed garnets (from four peridotites) with less than 4.0 wt percent are red or red-orange. Fifteen out of nineteen garnet peridotite inclusions, or 79 percent, contain purple garnets. The band of garnet compositions on the CaO-Cr_2O_3 plot (fig. 4B) is within or slightly more CaO-rich than the band of compositions of garnets from two-pyroxene assemblages (lherzolites) from Russian kimberlites (Sobolev and others, 1973). Peridotite garnets show an inverse relationship of Cr and Al (fig. 6B) owing to substitution in the six-coordinated position. Cr content is probably related to differences in bulk composition in the upper mantle.

Garnets from fresh peridotites have a bimodal distribution of CaO content (4.2 to 4.9 wt percent and 5.6 to 6.9 wt percent) (figs. 2C and 4B). Garnets from altered peridotites fill in part of the Ca gap for more Mg-rich compositions, but the Ca gap remains for lower Mg compositions (fig. 2C). The bimodal CaO distribution is reflected in Cr_2O_3 contents of more than 4.0 wt percent (fig. 4B) for 19 higher CaO garnets (all purple) and less than 3.1 wt percent Cr_2O_3 for six lower CaO garnets (red or red-orange). A similar bimodal distribution of Cr_2O_3 has been noted for Somerset Island, Canada kimberlites by Mitchell (1979, p. 163) as a justification for subdividing the garnets of group 9 ("chrome pyrope") of Dawson and Stephens (1975, 1976) into high and low Cr_2O_3 subgroups. The bimodal distribution may be present in sparse data shown by McCallum, Eggler and Burns (1975, p. 174) for garnets from peridotites in Colorado-Wyoming kimberlites.

Megacryst garnets -- Only six megacryst analyses are available. Colors are purple, red, red-orange, and orange. Five of the six megacrysts (size >1 cm) are pyrope-rich and have similar Ca contents; these plot in a line across the lower Ca portion of the peridotite garnet field (fig. 2C). All five contain less than 2.3 wt percent Cr_2O_3, and fit the Cr-poor group of garnet megacrysts (0.03-4.8 wt percent Cr_2O_3) in Colorado-Wyoming kimberlites (Eggler, McCallum, and Smith, 1979). The three with lowest Cr_2O_3 content (all red-orange and orange) are close in composition to peridotite garnets with similar low Cr_2O_3 contents (figs. 2C and 4B). The sixth megacryst is considerably more Fe-rich and Cr-poor, and is similar to garnet compositions from one of the mafic granulites in Williams diatremes (fig. 2C and 5B). The Fe-rich megacryst contains more Fe than the most Fe-rich megacrysts and xenocrysts from Kimberley, South Africa, kimberlites and is similar to the most Fe-rich garnets from Arizona kimberlites (Reid and Hanor, 1970, fig. 1). Additional analyses of megacrysts may fill in part of the gap. However, if megacrysts are fully represented in the colluvial garnet population (figs. 2A and 2B), a complete series between Mg-rich and Fe-rich megacrysts is not present. Cr-rich garnet megacrysts (6.3 to 13.0 wt percent Cr_2O_3) have been reported from Colorado-Wyoming kimberlites (Eggler, McCallum, and Smith, 1979, p. 215) but have not been found in the Williams kimberlites.

Garnets from granulites, mafic granulites and mafic amphibolites -- Granulites, mafic granulites and mafic amphibolites are rather common in the Williams 1 and 4 diatremes. Granulites have assemblages of garnet+clinopyroxene+plagioclase, and mafic granulites have garnet+ clinopyroxene$\pm$plagioclase. Both may contain small amounts of hypersthene, quartz, K-feldspar, rutile, amphibole, apatite, ilmenite, biotite, and carbonate. Mafic amphibolites have assemblages of garnet+amphibole and may contain small amounts of plagioclase, clinopyroxene, apatite, sphene, ilmenite, and carbonate.

Orange and red-orange garnets from three mafic granulites and orange garnets from two mafic amphibolites have been analyzed (table 5) and are iron-rich (fig. 2C), distinctly different from the peridotite garnets and most of the megacryst garnets. Granulite garnets show a small range of composition within each inclusion and have an overall range of 0.27 to 0.45 Mg/(Mg + Fe) and 5.0 to 8.4 wt percent CaO, with the two more Fe-rich samples being higher in Ca. Their Cr_2O_3 contents are less than 0.2 wt percent (fig. 5B), and MnO contents range from 0.4 to 0.7 wt percent. Analyses of garnets from other mafic granulites may fill in the small compositional gap between mafic granulites and may extend their range. However, compositions of colluvial garnets (figs. 2A and 2B), which are probably in part derived from mafic granulites, indicate that garnets of intermediate Mg/(Mg + Fe) (0.45 to 0.70) are rare or absent.

The two mafic amphibolites contain garnets that also show a small range of composition (table 5). These garnets contain more Ca, and equal or greater Fe compared to the granulite garnets (fig. 2C). Mafic amphibolite garnets have Mg/(Mg + Fe) of 0.17 to 0.20 (fig. 5B), contain less than 0.15 wt percent Cr_2O_3, and contain more MnO, 2.2 to 4.5 wt percent, than any other xenolith garnets analyzed so far.

Although mafic granulites that lack plagioclase can resemble eclogites in appearance, the granulite pyroxenes tend to be dark green rather than the gray-green or pale green color of eclogitic pyroxenes, and are low in the jadeite component ($NaAlSi_2O_6$) that is typical of eclogitic pyroxenes. The Ca-Mg-Fe contents of granulite garnets do not distinguish them from eclogite garnets. The granulite garnets plot within the area of Dawson and Stephens (1975, 1976) group 3, garnets dominantly from eclogites, but Dawson and Stephens did not include granulite garnets in the population used for their cluster group classification.

Garnets from other inclusions, Williams diatremes -- A garnet-diopside-phlogopite inclusion (H67-28E-3, table 5) is probably related to the garnet peridotite suite on the basis of similar pyrope content in the pink garnet. Although the Cr_2O_3 content (0.44 wt percent) is lower than any peridotite garnet or Mg-rich megacryst, the Cr_2O_3 content is higher than any of the mafic granulite garnets or amphibolite garnets (fig. 5B).

The Ca-Mg-Fe composition of pink garnet from a coarse-grained, garnet-rich, garnet-biotite-ilmenite-rutile inclusion (H67-50D, table 5) is close to garnet from one of the mafic granulites (fig. 2C), and contains low Cr_2O_3 (0.14 wt percent)(fig. 5B). This inclusion could be from the upper or lower crust.

Garnet-bearing inclusions, other diatremes

Two orthopyroxenites from the Bullwhacker Coulee diatreme (Hearn, 1979) contain entirely altered orthopyroxene, with small amounts of pink garnet and phlogopite in one, and in the other, small amounts of pink garnet, diopside and amphibole(?)(table 6B). The small ranges of garnet Mg/(Mg + Fe) values for each inclusion average 0.53 and 0.63 and are intermediate between peridotite garnets and granulite garnets (figs. 2C and 7A). Cr_2O_3 is 0.4 to 0.5 wt percent, higher than the Cr_2O_3 contents of garnets in mafic granulites (figs. 5B and 8A). Whether the orthopyroxenites are from the upper mantle or lower crust is unknown; the Cr_2O_3 content of garnets suggests that the inclusions originated from below upper crustal levels. Granulites and mafic granulites are found in Bullwhacker Coulee diatreme but their garnets have not yet been analyzed. Altered spinel peridotites are also present but are rare.

From Big Slide diatreme (Hearn, 1979), pink garnet (table 6A) in a felsic granulitic gneiss that is dominantly composed of K-feldspar, plagioclase, quartz, garnet and kyanite with small amounts of phlogopite, graphite, and rutile, has an intermediate Mg/(Mg + Fe) value of 0.38, and contains less CaO than garnets from granulites, pyroxenites or peridotites. Its Cr_2O_3 content is low, less than 0.2 wt percent. Garnets from granulites that are locally abundant in Big Slide diatreme have not yet been analyzed.

From Ervin Ridge 1 diatreme (Hearn, 1979), pink garnet (table 6C) from an inclusion of garnet-biotite-feldspar-sillimanite schist plots in the cluster of garnets from the Precambrian core of the Little Rocky Mountains (fig. 7C-see below). A single xenocryst of pink garnet (table 6C) from Bird Rapids 2 diatreme (Hearn, 1979) is slightly more Mg-rich than garnets of that cluster (fig. 7C).

Garnets from Precambrian rocks, Little Rocky Mountains

The tight cluster (fig. 7C) of garnets known or assumed to be derived from the Precambrian core of the Little Rocky Mountains contains data for three types of samples: (1) three orange garnets from garnet-kyanite-muscovite-quartz-feldspar schist outcropping in the Little Rocky Mountains, (2) two purple garnets that were collected from an anthill on the Thorsen dike and are probably residual from nearby terrace gravel deposits derived from the Little Rocky Mountains, and (3) a separate pink garnet and two pink garnets in pebbles of mica schist in conglomeratic sandstones of Fort Union Formation (Paleocene) that have been down-faulted several hundred meters along the borders of the Squaw Creek and Shellenberger Divide diatremes (Hearn, 1979). Clasts in these conglomeratic sandstones were probably derived from the Little Rocky Mountains. Garnets of all three types of samples, in spite of their range of colors (purple, pink, orange), all fall within the limited range of 0.18 to 0.29 Mg/(Mg + Fe), and are consistently low in CaO, all containing less than 2.3 wt percent. Cr_2O_3 is extremely low, less than 0.05 wt percent, except for one garnet from the Thorsen dike locality that contains 0.18 wt percent Cr_2O_3. MnO is variable, ranging from 0.55 to 1.48 wt percent.

Colluvial garnets from the Williams diatremes

Loose colluvial material was collected from the Williams 1 and 4 diatremes which are 700 m apart (fig. 1), to represent the colluvial garnet population that could be found downstream from the Williams diatremes. The samples were panned, sieved, and separated with heavy liquids. Approximately 700 garnet grains of 0.84 to 2.0 mm size were classified into six color groups by observation with a binocular microscope. The color groups used were: purple, red, pink, red-orange, orange, and light orange. Eighteen to twenty-two grains from each color group were analyzed for SiO_2, Al_2O_3, FeO, MgO, CaO, TiO_2, MnO, and Cr_2O_3 by electron microprobe. All tabulated analyses are averages of two to three analyses of each grain. No significant color variation was observed within grains, and no zoning was found by probe analysis. The chosen size range represents a common grain size of garnets in many types of xenoliths, but may bias the sample and could exclude representation of some xenoliths or megacrysts.

Chemical data from the six color groups of garnets from two samples of panned concentrates from Williams diatremes were tabulated (table 1) and plotted (figs. 2, 3, 4, 5, and 6) together for comparison among the color groups, comparison with garnets of known sources (tables 2, 3, and 5; figs. 2, 3, 4, 5, and 6), and comparison with garnets from other diatremes (table 6, figs. 7 and 8).

The purple garnets are the most distinctive group because of the high Cr_2O_3 content, and restricted ranges of MgO, FeO, and CaO. Purple garnets have a slightly larger range of Al_2O_3 contents than other groups, as a result of substitution of Cr for Al (fig. 6A). Twenty of twenty-one purple garnets (fig. 4) contain more than 2.4 wt percent Cr_2O_3, more than any of the analyzed red-orange, orange, or light-orange garnets. Sixteen of twenty-one purple garnets contain more Cr_2O_3 than any pink or red garnets. One purple garnet (W-GV-07) appears unique because it is much lower in CaO, has only 0.04 wt percent Cr_2O_3, and has much higher TiO_2 than any of the other purple garnets. It is similar to four red garnets (fig. 2B) and one light-orange garnet that also are very low in Cr_2O_3 and have more than 1.0 wt percent TiO_2.

The red and pink groups can both be divided into two sub-groups based on MgO and FeO content. The MgO-rich sub-group of each color is high in Cr_2O_3 but low in FeO (figs. 2B and 3). The MgO-rich subgroups are close to the purple garnet group in Ca-Mg-Fe composition (fig. 2). All of the MgO-rich pink garnets contain more than 0.7 wt percent Cr_2O_3. The FeO-rich sub-groups of the pink and red garnets are low in MgO and Cr_2O_3. Some of the FeO-rich pink garnets contain MnO values (1.7 to 1.9 wt percent) higher than any of the other analyzed colluvial garnets.

Garnets of the three orange groups (red-orange, orange, and light-orange) were the most difficult to distinguish from each other because they are gradational in color. The three color groups show considerable overlapping of compositional ranges (figs. 2A and 5A). All three orange groups have a small range of Al_2O_3, and have a smaller range of Cr_2O_3 than the purple, red, and pink groups (figs. 3 and 5A). As with the red and pink garnets, the three orange groups can be split into two subgroups based on relative FeO and MgO content. Almost all garnets of the MgO-rich subgroups have higher Cr_2O_3 content than the FeO-rich sub-groups (figs. 3 and 5A). The range of CaO of the three orange groups is similar to the range of CaO observed in the purple, red and pink garnets, although one orange and one light-orange garnet have higher CaO contents (figs. 2A and 2B).

Comparison of Williams colluvial garnets with garnets from known sources

The colluvial purple garnets and the Mg-rich, Cr-rich red and pink garnets show a remarkable correspondence with the peridotite and megacryst garnets (figs. 2B, 2C and 5). In addition, these colluvial garnets, peridotite garnets and megacryst garnets have the same trend of increasing Cr_2O_3 with increasing CaO (fig. 4); that trend is the lherzolitic trend of Sobolev and others (1973). However, some of the purple colluvial garnets (fig. 4A) fill in a gap in the CaO-Cr_2O_3 trend, between purple and red or red-orange garnets in peridotites (fig. 4B). All of the purple garnets from peridotites have CaO between 5.5 and 7.0 wt percent and Cr_2O_3 between 4.0 and 7.9 wt percent, whereas 19 of 21 purple colluvial garnets (figs. 3 and 4A) have generally lower values of CaO (4.5 to 6.1) and Cr_2O_3 (2.4 to 6.1). One colluvial garnet is higher in CaO (6.7) and is exceptionally high in Cr_2O_3 (9.9). Thus the colluvial purple garnets may, in part, represent disaggregated garnet peridotites which have not yet been found as xenoliths.

Cr-rich, Ca-poor garnets (group 10, low-calcium chrome-pyrope, Dawson and Stephens, 1975, 1976) have not been found in the Williams colluvial garnet suite. Such garnets are present in other kimberlites as xenocrysts, inclusions in diamond, and grains in garnet harzburgite or garnet dunite xenoliths, commonly with Cr-rich spinel also present (Finnerty and Boyd, 1980; McCallum and Eggler, 1976; Sobolev and others, 1973; Gurney and Switzer, 1973). Green garnets of high Ca and high Cr content (group 12, knorringitic uvarovite-pyrope, Dawson and Stephens, 1975, 1976) known from other localities (summarized in Clarke and Carswell, 1977) have not been found in the Williams kimberlite.

The Mg-rich sub-groups of pink, red, red-orange, orange and light orange colluvial garnets tend to be rich in Cr_2O_3 (fig. 3) and thus may be fragments of upper mantle rocks or fragments of megacrysts. Mg-rich pink garnets are richer in Mg and poorer in Ca than most of the purple garnets, and overlap part of the cluster of eight red garnets (fig. 2B). Eight of the ten Mg-rich pink garnets contain more than 1.7 wt percent Cr_2O_3, and all contain more than 0.7 wt percent Cr_2O_3. Of the main cluster of eight Mg-rich red garnets (fig. 2B), six contain more than 1.5 wt percent Cr_2O_3 and all contain more than 1 wt percent Cr_2O_3. A separate group of four Mg-rich red garnets and one purple garnet (fig. 2B) and one light orange garnet (fig. 2A) is distinctive in that those garnets contain less than 1 wt percent Cr_2O_3, contain 1.0 to 2.9 wt percent TiO_2 (higher than any of the Cr-rich red garnets), contain slightly higher Fe, and show variable Ca for nearly constant Mg/Fe. Three additional Mg-rich, Ti-rich, Cr-poor garnets (W-GT-67, W-GO-81, and W-GO-90, table 1) may belong to the same group but contain slightly higher Ca that places them in the main cluster of red-orange and orange Mg-rich garnets (fig. 2A). If these garnets are indeed related to each other, they may represent a series of bulk compositions that are related by fractionation of Ca. This group of six to nine Mg-rich, Ti-rich, Cr-poor garnets does not correspond with any analyzed xenoliths or megacrysts. Some of these garnets may fit cluster group 2 of Dawson and Stephens (1975, 1976), high-titanium pyrope (all examples are megacrysts or xenocrysts in kimberlite). These garnets may be close to cluster groups 25 or 50 of Danchin and Wyatt (1979), that contain garnets that are in part derived from ilmenite-bearing xenoliths.

Mg-rich red-orange, orange, and light-orange colluvial garnets (fig. 2A) overlap the lower Ca portion of the peridotite garnet field (fig. 2C) but none fall into the higher Ca portion of that field. The three orange groups of Mg-rich garnets overlap part of the megacryst trend of constant Ca with varying Mg/Fe and continue that trend to higher Fe content. The trend and position suggest that garnets of the three orange groups are fragments of megacrysts or are derived from garnet peridotites of generally lower Ca and Cr content. Separation of orange garnets into three color groups (red-orange, orange and light orange) has not yet delineated distinctly separate sources for each color group.

If the colluvial garnets contain a representative sample of fragments of megacrysts, then the megacrysts probably are bimodal in Mg/(Mg + Fe) and do not form a complete series of compositions between the five Mg-rich megacrysts and the one Fe-rich megacryst. Analyses of more megacrysts will test this conclusion.

Some of the Fe-rich colluvial red-orange, orange, and light-orange garnets (fig. 2A) are comparable in Ca-Mg-Fe composition to the mafic granulite garnets (fig. 2C). The low Cr content of Fe-rich colluvial red-orange, orange, and light-orange garnets is also similar to granulite garnets (figs. 5A and 5B). The three orange groups do not show any generally systematic differences in composition although the red-orange group has a higher proportion of Fe-rich, Cr-poor garnets (fig. 5A). The Fe-rich, Ca-poor pink garnets that are similar in composition to garnets from Precambrian rocks in the Little Rocky Mountains (figs. 2B and 7) are probably derived from Precambrian metamorphic rocks adjacent to the kimberlite at relatively shallow depths. None of the various colluvial garnets are similar to the mafic amphibolite garnets (fig. 2C). None of the Williams colluvial garnets are close in composition to garnets from orthopyroxenite inclusions in Bullwacker Coulee diatreme (fig. 7A) or from the felsic garnet-kyanite gneiss in Big Slide diatreme (fig. 7B). The colluvial garnet grains which are different from any of the analyzed garnets from inclusions (peridotites, granulites, amphibolites) may be from other rock types or megacrysts, which have not been analyzed or which have not been found as discrete xenoliths.

Panned concentrates from other diatremes

Limited numbers of garnets from panned concentrates of alluvium or colluvium from other diatremes were classified into color groups and analysed (table 6, figs. 7A, 7B, 8A, 8B) to determine whether garnets from upper mantle sources were present. Concentrates from Big Slide and Bullwhacker Coulee diatremes were selected because both diatremes are known to contain granulite inclusions of probable lower crustal origin, and Bullwhacker Coulee diatreme also contains altered spinel peridotite of upper mantle origin, and garnet orthopyroxenite of possible upper mantle origin.

Big Slide diatreme -- Although garnet peridotite inclusions have not yet been recognized in Big Slide diatreme, two analyzed garnets are of upper mantle origin. Both are purple, distinctly pyrope-rich (fig. 7B), chromium-rich (fig. 8B), and have Ca-Mg-Fe compositions similar to garnets from peridotites in the Williams diatremes (fig. 2C). These two garnets suggest that Big Slide diatreme probably contains other purple chromium-rich garnets and could contain garnet peridotite inclusions. Of the other analyzed garnets, one purple and several red, red-orange and orange garnets (fig. 7B) are close in composition to the garnets from mafic granulites from Williams diatremes (fig. 2C), and two are similar to orthopyroxenite garnets from Bullwhacker Coulee diatreme (fig. 7A). Two of the panned garnets are close to garnet from the felsic garnet-kyanite gneiss inclusion (fig. 7B).

Bullwhacker Coulee diatreme -- Only five garnets have been analyzed from a small concentrate of heavy minerals from colluvium; none are purple, and none are exceptionally rich in Cr_2O_3 (table 6B). One pink garnet is closely similar in Ca-Mg-Fe content (fig. 7A) to pink garnet from one of the orthopyroxenites and has similar Cr_2O_3 content (0.39 wt percent). The other four garnets have intermediate values of Mg/(Mg + Fe) and contain 0.25 or less wt percent Cr_2O_3. None of the garnets are compositionally similar to the garnets from three mafic granulites from the Williams diatremes (fig. 2C), although granulites and mafic granulites are the most abundant garnet-bearing inclusions in Bullwhacker Coulee diatreme. This suggests that garnets (not yet analyzed) from Bullwhacker Coulee granulites have higher Mg/(Mg + Fe) than garnets from Williams granulites and could extend the range of granulite garnets toward more Mg-rich compositions.

Conclusions

1. Garnet can be used rapidly and easily in the field as a tracer for kimberlite. Presence and color of garnet in surficial deposits and soils can indicate the presence of kimberlite.

2. Purple garnets are the most distinctive indicators of presence of kimberlite and its inclusions of upper mantle rocks and minerals. Most of the purple garnets are derived from garnet peridotites and are Mg-rich and contain more Cr (with Mg/(Mg + Fe) greater than 0.77, Cr_2O_3 greater than 1.5 wt percent) compared to garnets from other rock types. Purple colluvial garnets from the Williams diatremes are dominantly (20 of 21) Cr-rich. Fifteen of nineteen garnet peridotites contain purple garnet and four contain red or red-orange garnet.

3. Pink, red, red-orange, orange, and light-orange garnets can also be derived from kimberlite and its mantle inclusions but are not distinctive in color compared to garnets from more shallow sources. These five color groups show bimodal distribution of Fe and Mg; Mg-rich garnets (with Mg/(Mg + Fe) greater than 0.67) contain more Cr than most Fe-rich garnets and are probably fragments of upper mantle rocks or of megacrysts. The range of Ca-Mg-Fe compositions of colluvial Cr-rich purple, red, and pink garnets is closely similar to the Ca-Mg-Fe range of garnets from peridotite inclusions. Many of the Fe-rich garnets are compositionally similar to the range of garnets from lower-crustal mafic granulites and may be derived from them.

4. Garnets from garnet peridotites tend to have bimodal distribution of Ca and Cr. Similar bimodal distribution has been noted for peridotite garnets from kimberlites elsewhere in the world.

5. Megacryst garnets are purple, red, red-orange and orange. Five of six are Mg-rich; one is Fe-rich and is near to mafic granulite garnets in composition. Mg-rich megacrysts have less Cr_2O_3 (0.6 to 2.3 wt percent) than most garnets from garnet peridotites. Colluvial garnet compositions suggest that there is not a complete series of Ca-Mg-Fe compositions between Mg-rich and Fe-rich megacrysts.

6. The suite of colluvial garnets from the Williams diatremes is bimodal in Mg-Fe composition, with dominant ranges of Mg/(Mg + Fe) of 0.16 to 0.40 and 0.69 to 0.86. The two ranges are interpreted as reflecting the bulk compositional differences between the lower crust and upper mantle.

7. Big Slide diatreme contains two Mg-rich, Cr-rich purple garnets of probable peridotitic, upper mantle derivation in addition to the other analyzed colluvial-alluvial garnets that suggest a range of compositions of garnets from granulites and mafic granulites.

8. No purple, Cr-rich garnets have been found in limited sampling of Bullwhacker Coulee diatreme. Altered garnet-bearing orthopyroxenite inclusions contain garnet of intermediate Mg/(Mg + Fe) values. The few alluvial garnets analyzed suggest that garnets from mafic granulite inclusions are more Mg-rich than those from granulites in the Williams diatremes.

9. Garnets from shallow Precambrian rocks have a distinctive small range of Fe-rich, Ca-poor, Mg-poor compositions in spite of a range of colors (purple, pink, orange).

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Key to sample designation in tables:

Typical analysis number: B U - G P - 1 0 3

spaces: 1,2 3,4 5,6,7

Spaces 1,2: Locality

W	Williams diatremes
BS	Big Slide diatreme
BU	Bullwhacker Coulee diatreme
BI	Bird Rapids diatreme
E	Ervin Ridge diatreme
SC	Squaw Creek diatreme
SH	Shellenberger Divide diatreme
TH	Thorsen dike
LR	Little Rocky Mountains Precambrian

Space 3: Type of sample analyzed

G	Grains from panned concentrate, heavy-mineral separate, gravel, or anthill
P	Grain picked out of lithic sample
X	Xenocryst or megacryst
T	Thin section of inclusion

Space 4: Color group

V	Purple
R	Red
P	Pink
T	Red-orange
O	Orange
L	Light orange

Spaces 5, 6, 7: Analysis number, numbered consecutively for data for each locality.

Table 1.-- Analyses of colluvial garnets, Williams 1 and 4 diatremes, grouped by color[1]

SAMPLE	W-GV-01	W-GV-02	W-GV-03	W-GV-04	W-GV-05	W-GV-06	W-GV-07	W-GV-08	W-GV-09	W-GV-10	W-GV-11	W-GV-12	W-GV-13
SIO2	40.82	42.55	41.43	41.50	42.16	41.39	40.63	41.55	41.33	42.37	40.80	41.80	41.60
AL2O3	20.82	20.29	16.54	20.77	20.47	19.67	21.16	19.11	21.29	21.20	19.89	20.38	20.86
FEO	9.42	6.48	6.34	7.26	6.67	6.91	11.35	6.93	9.89	7.69	6.88	6.76	7.12
MGO	18.79	21.04	19.41	20.18	21.05	20.36	21.07	20.34	18.00	19.16	19.41	20.41	19.74
CAO	5.63	5.25	6.70	5.42	5.09	5.39	2.32	5.37	5.68	4.48	5.87	5.15	5.68
TIO2	0.15	0.49	0.47	0.02	0.61	0.29	2.79	0.61	0.11	0.80	0.00	0.69	0.00
MNO	0.46	0.26	0.32	0.41	0.27	0.26	0.29	0.29	0.69	0.29	0.39	0.30	0.43
CR2O3	3.93	4.12	9.89	4.64	3.68	5.01	0.04	4.86	2.79	2.44	5.68	3.86	4.93
TOTAL	100.02	100.48	101.10	100.20	100.00	99.28	99.65	99.06	99.78	98.43	98.92	99.35	100.36

CATIONS PER 12 OXYGENS													
SI	2.956	3.017	2.992	2.971	3.001	2.988	2.926	3.007	2.995	3.055	2.970	3.001	2.974
AL	1.776	1.696	1.407	1.752	1.718	1.674	1.793	1.629	1.818	1.800	1.707	1.724	1.757
FE	0.569	0.383	0.381	0.433	0.397	0.417	0.682	0.418	0.600	0.463	0.418	0.404	0.424
MG	2.027	2.224	2.089	2.154	2.236	2.191	2.260	2.194	1.944	2.059	2.106	2.186	2.105
CA	0.436	0.397	0.517	0.414	0.386	0.417	0.177	0.416	0.440	0.345	0.457	0.396	0.434
TI	0.006	0.025	0.025	0.000	0.031	0.015	0.150	0.032	0.004	0.042	0.000	0.036	0.000
MN	0.027	0.014	0.019	0.023	0.014	0.015	0.017	0.017	0.040	0.017	0.023	0.017	0.025
CR	0.223	0.229	0.563	0.263	0.207	0.286	0.002	0.278	0.159	0.137	0.325	0.217	0.277
TOTAL	8.020	7.985	7.993	8.010	7.990	8.003	8.007	7.991	8.000	7.918	8.006	7.981	7.996

SAMPLE	W-GV-14	W-GV-15	W-GV-16	W-GV-17	W-GV-18	W-GV-114	W-GV-115	W-GV-116	W-GR-19	W-GR-20	W-GR-21	W-GR-22	W-GR-23
SIO2	42.52	40.67	41.44	41.56	41.65	41.99	41.61	41.18	41.38	42.25	41.48	41.16	42.17
AL2O3	20.54	19.31	20.40	21.96	20.45	19.54	19.50	21.48	22.15	22.11	21.98	21.14	22.24
FEO	6.47	6.73	7.18	7.74	7.79	7.02	6.85	7.65	11.23	7.98	10.64	11.27	7.16
MGO	21.02	19.26	19.90	20.16	19.36	19.72	19.60	19.65	20.73	20.80	19.37	20.22	21.39
CAO	5.38	5.99	5.27	5.37	6.05	5.72	5.21	5.52	2.28	4.53	4.10	3.24	4.48
TIO2	0.43	0.59	0.71	0.04	0.06	0.15	0.12	0.01	1.71	0.80	1.54	2.89	0.66
MNO	0.27	0.26	0.26	0.38	0.46	0.64	0.89	0.39	0.27	0.27	0.30	0.27	0.28
CR2O3	4.13	6.09	3.95	3.02	4.35	5.86	5.81	2.64	0.06	1.61	0.93	0.08	2.09
TOTAL	100.76	98.90	99.11	100.23	100.17	100.64	99.59	98.52	99.81	100.35	100.34	100.27	100.47

CATIONS													
SI	3.004	2.964	2.991	2.963	2.990	3.006	3.007	2.987	2.962	2.990	2.970	2.948	2.975
AL	1.710	1.658	1.734	1.846	1.730	1.648	1.660	1.836	1.867	1.844	1.853	1.784	1.848
FE	0.381	0.408	0.432	0.460	0.468	0.420	0.413	0.464	0.672	0.471	0.636	0.674	0.422
MG	2.214	2.092	2.141	2.143	2.074	2.104	2.111	2.125	2.212	2.195	2.066	2.158	2.250
CA	0.406	0.466	0.406	0.410	0.463	0.438	0.403	0.428	0.174	0.342	0.313	0.248	0.337
TI	0.022	0.032	0.038	0.002	0.002	0.007	0.006	0.000	0.090	0.042	0.082	0.153	0.033
MN	0.014	0.015	0.015	0.023	0.027	0.039	0.054	0.023	0.015	0.014	0.017	0.015	0.016
CR	0.230	0.351	0.224	0.169	0.246	0.331	0.331	0.151	0.002	0.089	0.050	0.004	0.116
TOTAL	7.981	7.986	7.981	8.016	8.000	7.993	7.985	8.014	7.994	7.987	7.987	7.984	7.997

Table 1.-- Analyses of colluvial garnets, Williams 1 and 4 diatremes, grouped by color (continued)

SAMPLE	W-GR-24	W-GR-25	W-GR-26	W-GR-27	W-GR-28	W-GR-29	W-GR-30	W-GR-31	W-GR-32	W-GR-33	W-GR-34	W-GR-35	W-GR-36
SIO2	41.89	41.41	37.80	41.86	41.58	41.48	38.21	38.63	37.96	41.10	41.28	37.91	37.55
AL2O3	22.86	22.29	21.30	22.55	22.10	22.30	22.15	20.56	21.40	21.89	20.73	20.70	21.32
FEO	8.39	7.42	27.66	8.00	10.62	7.50	23.88	26.22	28.81	7.52	8.78	29.17	31.09
MGO	20.38	21.03	5.13	20.52	18.86	20.59	7.99	4.97	4.40	20.28	20.20	4.97	3.75
CAO	4.36	4.35	5.98	4.43	4.35	4.23	6.14	8.13	6.20	4.77	4.82	6.36	6.28
TIO2	0.80	0.72	0.06	0.50	1.02	0.64	0.13	0.11	0.07	0.63	0.91	0.09	0.03
MNO	0.26	0.20	0.86	0.23	0.33	0.28	0.48	0.52	0.74	0.34	0.29	0.76	0.89
CR2O3	1.22	1.77	0.01	1.09	0.61	1.55	0.09	0.02	0.00	2.80	3.31	0.02	0.02
TOTAL	100.16	99.19	98.80	99.18	99.47	98.57	99.07	99.16	99.58	99.33	100.32	99.98	100.93

CATIONS													
SI	2.970	2.960	2.999	2.992	2.998	2.982	2.962	3.044	2.998	2.950	2.958	2.996	2.965
AL	1.911	1.877	1.990	1.899	1.876	1.888	2.022	1.911	1.991	1.852	1.749	1.927	1.984
FE	0.497	0.442	1.834	0.478	0.639	0.449	1.547	1.728	1.903	0.451	0.525	1.927	2.054
MG	2.154	2.240	0.605	2.187	2.026	2.206	0.921	0.583	0.517	2.170	2.157	0.584	0.440
CA	0.331	0.331	0.507	0.337	0.334	0.325	0.509	0.685	0.524	0.367	0.368	0.538	0.531
TI	0.042	0.038	0.002	0.025	0.055	0.034	0.006	0.004	0.002	0.034	0.048	0.004	0.000
MN	0.014	0.010	0.056	0.012	0.019	0.017	0.029	0.035	0.048	0.019	0.017	0.048	0.058
CR	0.066	0.098	0.000	0.061	0.034	0.086	0.004	0.000	0.000	0.158	0.187	0.000	0.000
TOTAL	7.985	7.996	7.993	7.991	7.981	7.987	8.000	7.990	7.983	8.001	8.009	8.024	8.032

SAMPLE	W-GR-37	W-GP-38	W-GP-39	W-GP-40	W-GP-41	W-GP-42	W-GP-43	W-GP-44	W-GP-45	W-GP-46	W-GP-47	W-GP-48	W-GP-49
SIO2	38.68	37.86	37.41	37.44	36.84	37.59	39.10	36.56	41.17	42.21	41.87	42.20	41.78
AL2O3	21.84	21.85	21.57	21.21	20.92	21.73	22.63	21.15	21.76	22.03	22.14	21.84	21.29
FEO	26.84	22.36	32.98	33.15	33.02	25.04	20.71	33.88	7.45	7.31	7.41	7.54	7.63
MGO	6.23	7.48	6.25	5.82	4.96	7.70	10.17	3.73	21.50	22.03	21.97	21.44	21.39
CAO	7.57	7.84	0.80	1.14	1.44	5.59	6.24	1.77	4.47	4.54	4.64	4.49	4.75
TIO2	0.07	0.01	0.00	0.04	0.00	0.03	0.04	0.00	0.63	0.65	0.67	0.66	0.65
MNO	0.48	1.69	0.61	0.69	0.86	0.50	0.37	1.91	0.24	0.28	0.21	0.24	0.24
CR2O3	0.07	0.04	0.01	0.06	0.07	0.02	0.13	0.07	1.93	1.92	1.72	1.77	2.35
TOTAL	101.78	99.13	99.63	99.55	98.11	98.20	99.39	99.07	99.15	100.97	100.63	100.18	100.08

CATIONS													
SI	2.966	2.947	2.967	2.979	2.985	2.957	2.969	2.963	2.952	2.968	2.952	2.987	2.974
AL	1.974	2.003	2.015	1.989	1.998	2.015	2.026	2.019	1.839	1.824	1.839	1.821	1.785
FE	1.721	1.455	2.187	2.204	2.238	1.646	1.315	2.294	0.446	0.429	0.437	0.446	0.453
MG	0.711	0.868	0.737	0.688	0.599	0.902	1.150	0.449	2.297	2.310	2.309	2.262	2.270
CA	0.621	0.653	0.067	0.096	0.124	0.471	0.506	0.152	0.343	0.340	0.350	0.338	0.361
TI	0.002	0.000	0.000	0.002	0.000	0.000	0.002	0.000	0.033	0.033	0.035	0.035	0.033
MN	0.029	0.109	0.040	0.044	0.057	0.032	0.022	0.130	0.012	0.016	0.012	0.012	0.012
CR	0.002	0.002	0.000	0.002	0.002	0.000	0.006	0.002	0.109	0.105	0.095	0.097	0.131
TOTAL	8.026	8.037	8.013	8.004	8.003	8.023	7.996	8.009	8.031	8.025	8.029	7.998	8.019

Table 1.-- Analyses of colluvial garnets, Williams 1 and 4 diatremes, grouped by color (continued)

SAMPLE	W-GP-50	W-GP-51	W-GP-52	W-GP-53	W-GP-54	W-GP-55	W-GT-56	W-GT-57	W-GT-58	W-GT-59	W-GT-60	W-GT-61	W-GT-62
SIO2	41.48	41.69	42.46	36.49	42.55	42.59	41.33	41.41	38.40	41.67	38.32	42.29	38.60
AL2O3	20.76	21.66	21.72	21.06	23.90	23.61	22.91	22.65	21.99	23.14	22.34	22.92	22.06
FEO	6.73	6.79	6.59	33.95	7.41	8.13	11.34	8.71	27.43	10.30	25.27	8.07	23.83
MGO	20.80	20.57	21.09	3.94	21.64	20.56	18.95	20.41	6.28	19.75	7.30	21.29	8.52
CAO	5.02	4.83	4.64	1.20	4.66	4.63	4.49	4.61	6.03	4.34	6.50	4.14	6.29
TIO2	0.54	0.57	0.45	0.02	0.09	0.10	0.65	0.90	0.10	0.83	0.05	0.65	0.05
MNO	0.28	0.23	0.23	1.76	0.36	0.39	0.41	0.25	0.70	0.34	0.64	0.25	0.51
CR2O3	3.55	2.91	2.59	0.10	0.73	0.82	0.57	0.88	0.04	0.47	0.04	1.24	0.14
TOTAL	99.16	99.25	99.77	98.52	101.34	100.83	100.65	99.82	100.97	100.84	100.46	100.85	100.00
CATIONS													
SI	2.981	2.983	3.010	2.970	2.966	2.992	2.956	2.952	2.966	2.957	2.952	2.971	2.961
AL	1.756	1.826	1.813	2.021	1.963	1.955	1.931	1.902	2.002	1.934	2.027	1.897	1.995
FE	0.402	0.405	0.389	2.311	0.431	0.476	0.678	0.519	1.771	0.610	1.627	0.474	1.529
MG	2.227	2.193	2.228	0.478	2.248	2.153	2.021	2.169	0.723	2.088	0.836	2.229	0.975
CA	0.386	0.369	0.351	0.103	0.348	0.346	0.342	0.351	0.499	0.329	0.536	0.311	0.516
TI	0.027	0.029	0.022	0.000	0.004	0.004	0.033	0.048	0.004	0.043	0.002	0.033	0.002
MN	0.017	0.012	0.012	0.119	0.020	0.022	0.023	0.014	0.045	0.019	0.041	0.014	0.031
CR	0.200	0.164	0.143	0.004	0.039	0.045	0.031	0.048	0.002	0.025	0.000	0.068	0.006
TOTAL	7.996	7.981	7.968	8.006	8.019	7.993	8.015	8.003	8.012	8.005	8.021	7.997	8.015

SAMPLE	W-GT-63	W-GT-64	W-GT-65	W-GT-66	W-GT-67	W-GT-68	W-GT-69	W-GT-70	W-GT-71	W-GT-72	W-GT-73	W-GO-74	W-GO-75
SIO2	42.18	39.52	39.46	42.34	41.49	38.95	41.42	38.74	38.80	38.32	38.34	41.12	41.54
AL2O3	22.05	21.77	22.22	22.28	22.30	21.34	21.98	21.38	21.46	21.25	22.11	22.28	22.90
FEO	8.74	25.39	22.47	7.21	11.61	25.96	8.86	25.32	24.00	25.75	25.23	8.52	8.95
MGO	20.59	8.68	10.38	21.80	18.89	6.88	20.46	6.76	8.47	6.84	6.84	20.31	19.84
CAO	4.46	5.46	5.61	4.69	4.90	6.32	4.40	7.46	6.13	6.53	7.45	4.55	4.19
TIO2	0.81	0.08	0.07	0.66	1.23	0.08	0.82	0.14	0.10	0.11	0.10	0.73	0.75
MNO	0.33	0.70	0.47	0.23	0.34	0.77	0.29	0.55	0.50	0.66	0.52	0.27	0.27
CR2O3	1.52	0.17	0.16	1.86	0.05	0.00	0.66	0.06	0.04	0.06	0.07	1.37	0.61
TOTAL	100.68	101.77	100.84	101.07	100.81	100.30	98.89	100.41	99.50	99.52	100.66	99.15	99.05
CATIONS													
SI	2.987	2.991	2.974	2.967	2.967	3.011	2.984	2.993	2.995	2.991	2.953	2.957	2.979
AL	1.839	1.941	1.974	1.840	1.878	1.944	1.865	1.945	1.951	1.953	2.008	1.889	1.937
FE	0.518	1.605	1.416	0.421	0.692	1.676	0.533	1.635	1.550	1.678	1.625	0.510	0.537
MG	2.174	0.979	1.166	2.276	2.014	0.792	2.199	0.777	0.974	0.794	0.784	2.178	2.122
CA	0.336	0.442	0.451	0.352	0.375	0.521	0.338	0.617	0.505	0.545	0.615	0.350	0.320
TI	0.042	0.004	0.002	0.035	0.065	0.004	0.042	0.006	0.004	0.004	0.004	0.038	0.040
MN	0.019	0.044	0.028	0.012	0.019	0.050	0.017	0.034	0.031	0.043	0.034	0.015	0.015
CR	0.083	0.009	0.009	0.103	0.002	0.000	0.036	0.002	0.002	0.002	0.004	0.076	0.033
TOTAL	7.998	8.015	8.020	8.006	8.012	7.998	8.014	8.009	8.012	8.010	8.027	8.013	7.983

Table 1.-- Analyses of colluvial garnets, Williams 1 and 4 diatremes, grouped by color (continued)

SAMPLE	W-GO-76	W-GO-77	W-GO-78	W-GO-79	W-GO-80	W-GO-81	W-GO-82	W-GO-83	W-GO-84	W-GO-85	W-GO-86	W-GO-87	W-GO-88
SIO2	41.32	41.16	39.61	42.03	39.18	41.22	42.33	41.73	41.55	38.93	41.10	41.56	41.75
AL203	23.37	22.98	23.13	22.43	21.15	22.44	22.29	22.06	22.18	21.64	22.24	21.97	22.28
FEO	10.23	9.33	11.05	8.24	27.87	11.58	8.70	8.17	9.51	22.29	8.73	8.70	8.37
MGO	18.96	18.48	10.97	21.19	6.14	18.82	21.29	21.43	20.11	10.24	20.67	20.74	20.99
CAO	4.54	5.41	13.47	4.49	6.31	4.31	4.35	4.02	4.46	5.32	4.24	4.53	4.43
TIO2	0.65	0.72	0.27	0.68	0.07	0.90	0.79	0.75	0.94	0.04	0.80	0.84	0.77
MNO	0.30	0.24	0.25	0.32	0.83	0.36	0.27	0.27	0.33	0.63	0.28	0.25	0.27
CR203	0.32	0.37	0.02	1.04	0.05	0.13	0.84	0.80	0.75	0.20	0.87	0.90	0.77
TOTAL	100.19	98.69	98.77	100.42	101.60	99.76	100.86	99.23	99.83	99.29	98.93	99.49	99.63
CATIONS													
SI	2.982	2.978	2.956	2.975	3.015	2.972	2.985	2.982	2.975	2.980	2.959	2.975	2.979
AL	1.963	1.960	2.032	1.870	1.917	1.907	1.853	1.858	1.870	1.953	1.887	1.853	1.873
FE	0.609	0.563	0.688	0.486	1.793	0.698	0.513	0.486	0.569	1.427	0.524	0.519	0.498
MG	2.016	1.992	1.219	2.235	0.704	2.023	2.240	2.284	2.145	1.169	2.219	2.214	2.232
CA	0.345	0.418	1.075	0.340	0.519	0.332	0.327	0.306	0.340	0.436	0.325	0.347	0.337
TI	0.033	0.038	0.015	0.035	0.002	0.048	0.041	0.040	0.050	0.002	0.042	0.044	0.040
MN	0.017	0.013	0.015	0.019	0.052	0.021	0.014	0.015	0.019	0.040	0.017	0.015	0.015
CR	0.017	0.021	0.000	0.058	0.002	0.006	0.045	0.044	0.042	0.011	0.048	0.050	0.042
TOTAL	7.982	7.983	8.000	8.018	8.004	8.007	8.018	8.015	8.010	8.018	8.021	8.017	8.016

SAMPLE	W-GO-89	W-GO-90	W-GO-91	W-GL-92	W-GL-93	W-GL-94	W-GL-95	W-GL-96	W-GL-97	W-GL-98	W-GL-99	W-GL-100	W-GL-101
SIO2	41.77	41.39	42.02	42.38	41.11	41.79	41.63	38.78	42.32	42.01	39.12	41.05	40.23
AL203	21.85	22.20	22.66	22.17	22.70	22.88	22.48	21.42	22.73	22.26	21.98	22.29	22.38
FEO	8.56	12.55	10.59	8.89	11.80	12.01	12.62	22.93	8.46	8.62	25.40	12.71	13.49
MGO	21.11	18.30	19.82	20.79	18.64	18.68	18.18	4.75	20.11	20.90	10.88	17.83	17.23
CAO	4.18	5.14	4.54	4.42	4.17	4.10	4.13	11.29	5.65	4.25	2.03	4.17	4.25
TIO2	0.78	1.10	0.73	0.52	0.54	0.44	0.49	0.06	0.73	0.71	0.00	0.47	0.46
MNO	0.27	0.38	0.34	0.29	0.38	0.37	0.46	0.94	0.28	0.30	0.75	0.42	0.45
CR203	0.74	0.10	0.82	0.72	0.28	0.23	0.59	0.09	0.13	0.86	0.11	1.11	0.22
TOTAL	99.26	101.16	101.52	100.18	99.62	100.50	100.58	100.26	100.41	99.91	100.27	100.05	98.71
CATIONS													
SI	2.990	2.965	2.971	3.007	2.970	2.992	2.991	3.004	2.996	2.987	2.978	2.974	2.960
AL	1.842	1.874	1.888	1.854	1.931	1.929	1.905	1.956	1.897	1.866	1.973	1.902	1.941
FE	0.510	0.750	0.624	0.527	0.712	0.718	0.757	1.485	0.500	0.511	1.617	0.769	0.829
MG	2.252	1.956	2.089	2.199	2.007	1.994	1.947	0.548	2.124	2.216	1.235	1.926	1.889
CA	0.319	0.393	0.342	0.335	0.322	0.313	0.316	0.937	0.428	0.323	0.165	0.323	0.334
TI	0.042	0.059	0.037	0.027	0.027	0.023	0.025	0.002	0.037	0.037	0.000	0.025	0.023
MN	0.015	0.023	0.019	0.017	0.023	0.021	0.027	0.061	0.017	0.017	0.047	0.025	0.028
CR	0.040	0.004	0.045	0.040	0.015	0.012	0.034	0.004	0.006	0.048	0.004	0.063	0.011
TOTAL	8.010	8.024	8.015	8.006	8.007	8.002	8.002	7.997	8.005	8.005	8.019	8.007	8.015

Table 1.-- Analyses of colluvial garnets, Williams 1 and 4 diatremes, grouped by color (continued)

SAMPLE	W-GL-102	W-GL-103	W-GL-104	W-GL-105	W-GL-106	W-GL-107	W-GL-108	W-GL-109	W-GL-110	W-GL-111	W-GL-112	W-GL-113
SIO2	41.11	41.51	41.45	38.61	41.24	41.58	40.82	41.52	41.20	38.64	41.04	40.65
AL2O3	22.49	22.03	22.39	21.05	22.14	21.18	21.82	22.37	22.63	21.36	22.51	23.15
FEO	11.65	8.37	11.95	27.26	12.55	10.06	11.41	12.88	12.23	27.04	12.59	16.04
MGO	20.04	20.38	18.73	5.51	17.66	19.30	18.21	18.43	18.58	5.78	18.56	12.60
CAO	2.57	4.49	4.38	7.35	4.21	5.20	4.55	4.19	4.19	6.27	4.16	8.42
TIO2	1.16	0.66	0.45	0.07	0.43	0.95	0.52	0.51	0.59	0.07	0.42	0.10
MNO	0.30	0.28	0.42	0.69	0.45	0.34	0.38	0.46	0.34	0.77	0.39	0.40
CR2O3	0.26	1.25	0.51	0.04	0.61	1.16	1.46	0.38	0.28	0.09	0.13	0.05
TOTAL	99.58	98.97	100.28	100.58	99.29	99.77	99.17	100.74	100.04	100.02	99.80	101.41
CATIONS												
SI	2.958	2.984	2.981	3.007	3.003	2.997	2.973	2.982	2.972	3.012	2.972	2.972
AL	1.906	1.868	1.898	1.931	1.900	1.798	1.872	1.892	1.922	1.962	1.922	1.993
FE	0.701	0.502	0.718	1.773	0.763	0.604	0.694	0.773	0.736	1.761	0.761	0.980
MG	2.149	2.184	2.010	0.637	1.917	2.073	1.977	1.972	1.999	0.670	2.005	1.373
CA	0.198	0.346	0.335	0.612	0.327	0.402	0.354	0.322	0.322	0.523	0.323	0.659
TI	0.061	0.034	0.023	0.002	0.021	0.050	0.027	0.027	0.032	0.002	0.021	0.004
MN	0.017	0.017	0.025	0.043	0.025	0.019	0.021	0.027	0.019	0.050	0.023	0.023
CR	0.015	0.069	0.027	0.002	0.034	0.065	0.083	0.021	0.015	0.004	0.006	0.002
TOTAL	8.005	8.004	8.017	8.007	7.990	8.008	8.001	8.016	8.017	7.984	8.033	8.006

1/
Analyses are in order of color groups: purple, red, pink, red-orange, orange, light orange. Analyses 114, 115 and 116 follow analysis 18.

Analyses 1-16, 19-36, 38-53, 56-89, 92-112, 114, 115: Garnets from H68-16N, colluvial material west of southwestern end of Williams 4 dike-like diatreme, southwest of autolith-rich breccia; NW1/4 SW1/4 NE1/4 sec. 7, T. 24N., R. 24E.

Analyses 17, 18, 37, 54, 55, 90, 91, 113, 116: Garnets from H68-17C, colluvial lag material in topographic saddle between terrace-pediment gravel remnants, south-central part of Williams 1 diatreme; NW1/4 SW1/4 NW1/4 sec. 8,T. 24N., R. 24E.

Table 2.-- Analyses of garnets from fresh garnet peridotites, Williams 1 and 4 diatremes[1]

SAMPLE	W-PV-117[2]	W-PV-118[3]	W-PV-119[4]	W-PV-120[5]	W-PV-121[6]	W-PV-122[7]	W-PV-123[7]	W-PR-124[8]	W-PT-125[9]	W-PT-126[9]
SIO2	41.36	41.11	41.27	41.53	40.99	41.99	41.71	40.88	42.26	41.95
AL2O3	19.09	16.67	17.59	18.23	18.58	18.96	19.03	20.34	21.76	21.78
FEO	7.27	6.23	6.22	6.23	5.68	6.13	6.11	9.62	8.45	8.03
MGO	19.61	19.92	20.57	21.17	21.43	20.30	19.67	19.59	21.17	21.39
CAO	6.32	6.91	6.57	5.96	5.71	6.53	6.41	4.86	4.38	4.23
TIO2	0.00	0.18	0.17	0.42	0.50	0.23	0.23	0.48	0.70	0.57
MNO	0.50	0.30	0.30	0.29	0.28	0.51	0.60	0.39	0.30	0.29
CR2O3	5.58	7.83	6.60	5.84	6.22	6.43	6.38	3.03	0.69	0.79
TOTAL	99.73	99.15	99.29	99.67	99.39	101.08	100.14	99.19	99.71	99.03
CATIONS PER 12 OXYGENS										
SI	2.997	3.011	3.003	2.997	2.962	2.994	3.001	2.975	3.010	3.003
AL	1.630	1.439	1.509	1.551	1.582	1.593	1.613	1.745	1.827	1.838
FE	0.441	0.382	0.379	0.376	0.343	0.365	0.367	0.585	0.503	0.481
MG	2.118	2.175	2.232	2.278	2.309	2.157	2.110	2.126	2.248	2.283
CA	0.491	0.542	0.512	0.461	0.442	0.498	0.493	0.379	0.334	0.324
TI	0.000	0.010	0.009	0.023	0.027	0.012	0.012	0.026	0.037	0.031
MN	0.031	0.019	0.018	0.018	0.017	0.030	0.036	0.024	0.018	0.018
CR	0.320	0.454	0.380	0.333	0.355	0.362	0.362	0.174	0.039	0.045
TOTAL	8.028	8.032	8.042	8.037	8.037	8.011	7.994	8.034	8.016	8.023

1/ Analyses 117-120, 124, 125 from Hearn and Boyd (1975); analyses 121, 126 by F.R. Boyd, unpublished.

2/ Garnet lherzolite, granular texture, Williams 4 diatreme, W1/2 NE1/4 sec. 7, T. 24 N., R. 24 E., field no. H68-16B.

3/ Garnet lherzolite, granular with necklace texture, Williams 4, field no. H67-28K-1.

4/ Garnet lherzolite, granular with necklace texture, Williams 4, field no. H67-28I-2.

5/ Garnet lherzolite, sheared texture, Williams 1 diatreme, W1/2 NW1/4 sec. 8, T. 24 N., R. 24 E, field no. H69-15F.

6/ Garnet lherzolite, sheared texture, Williams 1, field no. H68-17D-2.

7/ Garnet lherzolite, granular with necklace texture, Williams 4, field no. H79-6C-1.

8/ Orthopyroxene-rich garnet peridotite or olivine-garnet orthopyroxenite, granular texture, Williams 4, field no. H67-28K-4.

9/ Garnet lherzolite, sheared texture, Williams 4, field no. H67-28K-3.

Table 3.-- Analyses of garnets from altered garnet peridotites, Williams 4 diatreme[1,2]

SAMPLE	W-PV-127	W-PV-128	W-PV-129	W-PV-130	W-PV-131	W-PV-132	W-PV-133	W-PV-134	W-PV-135	W-PV-136	W-PV-137	W-PV-141	W-PR-138
SIO2	42.62	42.45	41.79	41.63	42.10	42.19	41.65	42.10	41.92	42.45	40.53	40.91	42.29
AL2O3	19.09	19.38	19.81	19.05	19.05	20.48	19.81	20.17	18.07	18.88	18.38	18.19	21.81
FEO	6.10	6.93	6.40	7.30	7.84	6.17	6.55	6.95	6.39	6.40	8.19	6.18	6.89
MGO	21.56	19.53	20.29	19.32	19.15	20.04	20.06	20.22	20.01	21.03	18.24	21.21	21.43
CAO	5.66	6.75	5.85	6.73	6.39	6.09	5.86	5.94	6.77	5.74	6.32	5.58	4.83
TIO2	0.60	0.00	0.48	0.11	0.11	0.15	0.00	0.00	0.13	0.56	0.16	0.67	0.57
MNO	0.49	0.42	0.56	0.93	0.83	0.23	0.54	0.36	0.27	0.35	0.34	0.29	0.50
CR2O3	5.32	6.31	4.26	6.55	6.30	5.37	6.08	5.65	7.30	5.93	6.55	6.34	1.84
TOTAL	101.44	101.77	99.44	101.62	101.77	100.72	100.55	101.39	100.86	101.34	98.71	99.37	100.16
CATIONS PER 12 OXYGENS													
SI	3.010	3.012	3.007	2.977	3.004	2.997	2.980	2.986	3.007	3.009	2.990	2.965	2.994
AL	1.588	1.620	1.680	1.605	1.601	1.714	1.671	1.685	1.527	1.577	1.598	1.554	1.819
FE	0.360	0.411	0.385	0.436	0.468	0.366	0.392	0.412	0.383	0.379	0.505	0.375	0.407
MG	2.269	2.065	2.177	2.060	2.037	2.122	2.140	2.138	2.139	2.222	2.006	2.292	2.262
CA	0.428	0.512	0.451	0.515	0.488	0.463	0.449	0.451	0.520	0.435	0.499	0.433	0.366
TI	0.032	0.000	0.026	0.005	0.006	0.007	0.000	0.000	0.007	0.029	0.008	0.037	0.030
MN	0.029	0.025	0.034	0.056	0.050	0.013	0.032	0.021	0.016	0.020	0.021	0.018	0.029
CR	0.296	0.353	0.242	0.370	0.355	0.301	0.343	0.316	0.413	0.332	0.381	0.363	0.103
TOTAL	8.012	7.998	8.002	8.024	8.009	7.983	8.007	8.009	8.012	8.003	8.008	8.037	8.010

SAMPLE	W-PR-139	W-PT-140
SIO2	42.10	42.08
AL2O3	21.44	21.83
FEO	7.11	6.45
MGO	21.59	21.87
CAO	4.80	4.64
TIO2	0.60	0.50
MNO	0.28	0.13
CR2O3	1.99	2.14
TOTAL	99.91	99.64
CATIONS		
SI	2.991	2.985
AL	1.795	1.825
FE	0.422	0.382
MG	2.286	2.313
CA	0.365	0.352
TI	0.032	0.026
MN	0.017	0.007
CR	0.111	0.120
TOTAL	8.019	8.010

1/ Analysis no. followed by field no.: 127, H67-28A-6; 128 and 129, H67-28A-7; 130 and 131, H67-28E-11; 132, H67-28E-14; 133 and 134, H67-28E-16; 135, H67-28E-17; 136, H67-28E-18; 137, H67-28E-12; 138 and 139, H73-2M; 140, H67-28A-5; 141, H73-2F.

2/ Analysis 141 by F.R. Boyd, unpublished.

Table 4.-- Analyses of garnet megacrysts, Williams 4 diatreme[1,2]

SAMPLE	W-XV-142	W-XR-143	W-XT-144	W-XT-145	W-XT-146	W-XO-147
SIO2	42.55	42.37	41.90	42.01	39.05	41.86
AL2O3	21.44	21.47	21.76	22.04	21.05	21.45
FEO	5.64	7.00	8.57	8.36	22.22	8.66
MGO	22.44	22.04	20.37	20.91	9.67	20.76
CAO	4.84	4.93	4.52	4.52	5.98	4.50
TIO2	0.29	0.45	0.49	0.67	0.08	0.70
MNO	0.26	0.30	0.32	0.32	0.87	0.29
CR2O3	2.13	2.24	0.74	0.80	0.10	0.66
TOTAL	99.59	100.80	98.67	99.63	99.02	98.88
CATIONS PER 12 OXYGENS						
SI	3.011	2.986	3.019	2.996	3.009	3.012
AL	1.783	1.783	1.848	1.853	1.912	1.819
FE	0.334	0.412	0.516	0.499	1.432	0.521
MG	2.368	2.315	2.188	2.223	1.111	2.227
CA	0.367	0.372	0.349	0.345	0.494	0.347
TI	0.015	0.024	0.027	0.036	0.005	0.038
MN	0.016	0.018	0.020	0.019	0.057	0.018
CR	0.119	0.125	0.042	0.045	0.006	0.038
TOTAL	8.018	8.035	8.009	8.016	8.026	8.020

1/ Analysis no. followed by field no.:142, H67-28J-2; 143, H67-28J-4; 144, H67-28B; 145, H67-28J-1; 146, P64-40H-1; 147, H67-28J-3.

2/ Analyses 143 and 144 from Hearn and Boyd (1975), analyses 142, 145-147 by F.R. Boyd, unpublished.

Table 5.-- An lyses of garnets from other inclusions, Williams 1 and 4 diatremes [1]

SAMPLE	W-PP-148 [2]	W-PP-149 [3]	W-TO-150 [4]	W-TO-151 [4]	W-TO-152 [4]	W-TT-153 [5]	W-TT-154 [5]	W-TT-155 [5]	W-TT-156 [6]	W-TT-157 [6]	W-TT-158 [6]	W-TO-159 [8]	W-TO-160 [8]
SIO2	42.23	38.91	39.08	39.15	39.94	38.93	38.82	38.64	38.40	37.99	38.46	38.11	38.42
AL2O3	22.28	21.09	22.10	22.46	22.36	21.62	21.48	21.38	21.38	21.80	21.18	21.00	21.21
FEO	8.32	24.56	24.61	23.97	23.23	26.85	24.88	26.42	25.41	25.18	26.65	26.16	26.62
MGO	19.62	8.35	9.14	10.25	10.28	6.20	7.21	6.75	5.45	6.77	5.91	3.23	3.37
CAO	5.28	4.98	5.13	4.97	5.39	6.93	6.81	6.62	8.33	6.85	7.41	9.52	9.38
TIO2	0.13	0.04	0.09	0.06	0.09	0.07	0.08	0.21	0.03	0.07	0.10	0.06	0.04
MNO	0.38	0.51	0.48	0.48	0.46	0.54	0.52	0.56	0.70	0.59	0.58	2.59	2.08
CR2O3	0.44	0.14	0.06	0.16	0.08	0.02	0.03	0.04	0.07	0.09	0.04	0.07	0.06
TOTAL	98.68	98.58	100.69	101.50	101.83	101.16	99.83	100.62	99.77	99.34	100.33	100.74	101.18
CATIONS PER 12 OXYGENS													
SI	3.039	3.030	2.976	2.947	2.983	2.997	3.002	2.985	3.001	2.964	2.995	2.997	3.002
AL	1.889	1.935	1.981	1.993	1.968	1.961	1.957	1.945	1.968	2.004	1.943	1.946	1.953
FE	0.501	1.599	1.566	1.509	1.451	1.729	1.607	1.707	1.661	1.642	1.735	1.720	1.739
MG	2.105	0.969	1.037	1.149	1.144	0.711	0.831	0.777	0.633	0.788	0.686	0.378	0.392
CA	0.407	0.415	0.417	0.400	0.432	0.571	0.563	0.546	0.697	0.572	0.617	0.801	0.785
TI	0.007	0.002	0.004	0.002	0.004	0.002	0.003	0.011	0.000	0.002	0.004	0.003	0.002
MN	0.023	0.034	0.029	0.028	0.028	0.034	0.033	0.036	0.045	0.039	0.036	0.172	0.137
CR	0.025	0.009	0.002	0.009	0.004	0.000	0.001	0.002	0.002	0.004	0.002	0.004	0.003
TOTAL	7.996	7.993	8.012	8.037	8.014	8.005	7.997	8.009	8.007	8.015	8.018	8.021	8.013

SAMPLE	W-TO-161 [8]	W-TO-162 [7]	W-TO-163 [7]	W-TO-164 [7]	W-TO-165 [8]	W-TO-166 [8]	W-TO-167 [8]
SIO2	38.07	38.13	38.14	38.01	38.46	38.39	37.94
AL2O3	21.03	21.02	21.13	20.90	21.19	21.31	21.13
FEO	25.57	22.53	22.95	22.79	26.28	26.41	25.50
MGO	3.24	2.95	3.07	3.14	3.39	3.54	3.15
CAO	10.20	11.02	10.76	10.42	9.43	9.01	10.14
TIO2	0.03	0.06	0.04	0.05	0.05	0.03	0.07
MNO	2.21	4.51	4.28	4.50	2.27	2.27	2.16
CR2O3	0.05	0.04	0.05	0.10	0.13	0.00	0.09
TOTAL	100.40	100.26	100.42	99.91	101.20	100.96	100.18
CATIONS							
SI	2.997	3.002	2.997	3.003	3.003	3.002	2.992
AL	1.951	1.950	1.956	1.945	1.950	1.964	1.963
FE	1.683	1.483	1.508	1.505	1.716	1.726	1.682
MG	0.360	0.346	0.360	0.370	0.394	0.412	0.369
CA	0.860	0.929	0.906	0.882	0.788	0.755	0.856
TI	0.001	0.003	0.002	0.003	0.002	0.001	0.004
MN	0.147	0.300	0.284	0.301	0.149	0.150	0.144
CR	0.003	0.002	0.003	0.006	0.007	0.000	0.005
TOTAL	8.022	8.015	8.016	8.015	8.009	8.010	8.015

1/ Analyses 148 and 149 by F.R. Boyd, unpublished.

2/ Garnet-diopside-phlogopite inclusion, Williams 4, field no. H67-28E-3.

3/ Garnet-biotite-ilmenite(?)-rutile inclusion, garnet-rich, Williams 1, field no. H67-50D.

4/ Garnet-clinopyroxene-rutile granulite, Williams 4, field no. H67-28J-1.

5/ Garnet-clinopyroxene-plagioclase-quartz(?)-rutile granulite, Williams 4, field no. H67-28H-1.

6/ Garnet-clinopyroxene-plagioclase-K feldspar(?)-biotite-carbonate-rutile granulite, Williams 1, field no. H67-17A-7A.

7/ Garnet-carbonate-apatite-clinopyroxene(?) amphibolite, Williams 4, field no. H67-28D-2.

8/ Garnet-plagioclase-carbonate-apatite amphibolite, Williams 4, field no. H67-28D-1.

Table 6A.-- Analyses of garnets from Big Slide .1 diatreme, SW1/4 SE1/4 sec. 22 and NW1/4 NE1/4 sec. 27, T. 24N., R. 19 E. [1]

SAMPLE	BS-GV-01	BS-GV-02	BS-GV-03	BS-GV-18	BS-GR-04	BS-GR-05	BS-PP-06	BS-PP-07	BS-PP-08	BS-GP-09	BS-GP-10	BS-GP-11	BS-GT-12
SIO2	40.96	38.68	38.45	41.24	39.06	39.02	39.16	39.30	39.22	40.34	39.04	39.24	38.88
AL2O3	17.54	21.71	20.89	20.98	22.01	22.00	21.92	21.72	21.90	22.86	22.26	22.55	21.78
FEO	7.89	25.39	28.69	7.62	25.04	23.00	26.69	26.88	26.76	19.11	27.31	26.54	24.06
MGO	19.41	5.87	6.13	19.40	7.92	9.11	9.33	9.31	9.43	12.66	8.36	9.93	8.21
CAO	6.25	7.76	5.23	5.59	6.17	5.24	2.30	2.26	2.18	4.84	3.43	1.96	6.02
TIO2	1.23	0.08	0.05	0.05	0.10	0.07	0.01	0.00	0.00	0.05	0.02	0.02	0.08
MNO	0.39	0.50	0.56	0.43	0.52	0.56	0.30	0.27	0.42	0.49	0.20	0.22	0.39
CR2O3	7.30	0.02	0.07	3.67	0.00	0.25	0.04	0.00	0.07	0.42	0.14	0.01	0.02
TOTAL	100.97	100.01	100.07	98.98	100.82	99.25	99.75	99.74	99.98	100.77	100.76	100.47	99.44
CATIONS PER 12 OXYGENS													
SI	2.960	3.002	3.009	2.987	2.985	2.996	3.010	3.023	3.009	2.984	2.988	2.986	2.998
AL	1.493	1.986	1.927	1.791	1.982	1.989	1.986	1.968	1.980	1.992	2.008	2.023	1.978
FE	0.477	1.646	1.877	0.461	1.599	1.475	1.715	1.729	1.717	1.181	1.748	1.688	1.550
MG	2.091	0.679	0.714	2.095	0.901	1.043	1.069	1.068	1.079	1.396	0.952	1.125	0.943
CA	0.483	0.645	0.437	0.433	0.504	0.430	0.189	0.185	0.179	0.382	0.281	0.158	0.495
TI	0.065	0.004	0.002	0.002	0.004	0.002	0.000	0.000	0.000	0.002	0.000	0.000	0.004
MN	0.023	0.032	0.037	0.026	0.031	0.036	0.019	0.017	0.027	0.030	0.011	0.013	0.024
CR	0.416	0.000	0.002	0.210	0.000	0.013	0.002	0.000	0.004	0.023	0.006	0.000	0.000
TOTAL	8.008	7.994	8.005	8.005	8.006	7.984	7.990	7.990	7.995	7.990	7.994	7.993	7.992

SAMPLE	BS-GT-13	BS-GT-14	BS-GO-15	BS-GO-16	BS-GO-17	BS-GO-19
SIO2	38.18	38.60	39.40	40.14	39.68	39.33
AL2O3	21.49	21.03	21.89	23.00	22.23	21.21
FEO	23.97	27.78	22.15	20.86	21.95	23.12
MGO	7.01	5.89	9.43	11.74	9.50	9.48
CAO	7.23	6.38	7.16	5.29	6.76	5.36
TIO2	0.14	0.09	0.07	0.09	0.06	0.05
MNO	0.38	0.52	0.35	0.49	0.55	0.43
CR2O3	0.04	0.13	0.22	0.23	0.09	0.00
TOTAL	98.44	100.42	100.67	101.84	100.82	98.98
CATIONS						
SI	2.988	3.008	2.981	2.967	2.994	3.029
AL	1.982	1.930	1.951	2.004	1.975	1.925
FE	1.568	1.809	1.401	1.288	1.384	1.489
MG	0.817	0.684	1.063	1.292	1.067	1.088
CA	0.606	0.530	0.579	0.418	0.544	0.442
TI	0.007	0.004	0.002	0.004	0.002	0.002
MN	0.023	0.032	0.022	0.030	0.035	0.028
CR	0.002	0.007	0.011	0.013	0.004	0.000
TOTAL	7.993	8.004	8.010	8.016	8.005	8.003

1/
Analyses 1-5, 9-18: Panned concentrate from coarse alluvium in gully northwest of east breccia pipe, field no. H67-17A.
Analyses 6-8: Garnet-kyanite-quartz-K feldspar-plagioclase granulitic gneiss with accessory phlogopite, rutile and graphite, field no. H69-8C-2.
Analysis 19: Panned concentrate, from surface of west slope of east breccia pipe, field no. H69-8B-4.

Table 6B.-- Analyses of garnets from Bullwhacker Coulee diatreme, NE1/4 SE1/4 sec. 33, T. 24N., R. 21E. [1]

SAMPLE	BU-PP-01	BU-PP-02	BU-GP-03	BU-GP-04	BU-GP-05	BU-PP-06	BU-PP-07	BU-PP-08	BU-GO-09	BU-GL-10
SIO2	41.06	40.55	40.11	39.44	39.58	40.02	39.68	39.91	39.54	40.25
AL2O3	22.92	23.06	23.03	22.44	22.69	22.37	22.34	22.14	21.93	22.53
FEO	15.84	16.41	21.15	24.22	19.13	18.89	19.02	19.45	21.02	15.87
MGO	15.69	14.94	14.15	10.91	12.76	12.36	12.23	11.77	10.71	13.26
CAO	4.39	4.84	2.08	3.53	4.71	4.66	4.81	4.64	4.77	5.65
TIO2	0.00	0.00	0.04	0.02	0.09	0.01	0.00	0.02	0.09	0.13
MNO	0.63	0.69	0.20	0.32	0.61	0.82	0.77	0.90	0.22	0.47
CR2O3	0.41	0.49	0.03	0.09	0.39	0.48	0.46	0.48	0.00	0.25
TOTAL	101.44	100.98	100.79	100.97	99.96	99.61	99.31	99.31	98.28	98.61
CATIONS PER 12 OXYGENS										
SI	2.974	2.962	2.967	2.972	2.960	2.998	2.987	3.009	3.025	3.008
AL	1.956	1.985	2.008	1.992	2.000	1.975	1.982	1.967	1.977	1.984
FE	0.958	1.001	1.308	1.526	1.197	1.183	1.197	1.226	1.344	0.991
MG	1.694	1.627	1.560	1.225	1.422	1.379	1.372	1.323	1.222	1.477
CA	0.378	0.377	0.165	0.283	0.377	0.374	0.386	0.374	0.391	0.468
TI	0.000	0.000	0.002	0.000	0.005	0.000	0.000	0.000	0.004	0.007
MN	0.038	0.041	0.012	0.020	0.039	0.050	0.048	0.057	0.014	0.030
CR	0.023	0.028	0.002	0.004	0.023	0.028	0.026	0.028	0.000	0.015
TOTAL	8.021	8.021	8.024	8.022	8.023	7.987	7.998	7.984	7.977	7.980

1/ Analyses 1 and 2: Altered garnet-phlogopite orthopyroxenite(?), field no. H68-6A.
Analyses 3-5, 9 and 10: Panned concentrate, east breccia pipe, field no. H71-21G.
Analyses 6-8: Altered amphibole-clinopyroxene orthopyroxenite(?), field no. H71-21B.

Table 6C.-- Analyses of garnets from other inclusions, Precambrian bedrock, terrace deposits and Paleocene sedimentary rocks.

SAMPLE	BI-XP-01[1]	E-PP-01[2]	E-PP-02[2]	E-PP-03[2]	LR-PO-01[3]	LR-PO-02[3]	LR-PO-03[3]	SC-PP-01[4]	SC-PP-02[4]	SH-PP-01[5]	TH-GV-01[6]	TH-GV-02[6]
SIO2	38.71	38.41	37.87	37.60	37.61	37.59	37.83	37.89	38.06	38.15	37.35	38.42
AL2O3	22.31	21.48	21.36	21.64	21.42	21.70	21.71	21.85	21.72	21.44	21.52	21.83
FEO	27.31	33.04	32.60	32.68	33.98	34.38	33.46	33.36	34.10	35.18	32.59	31.40
MGO	8.44	5.13	4.77	5.26	4.79	4.56	4.89	4.89	4.43	4.80	5.70	7.21
CAO	2.77	2.14	1.83	2.07	1.51	1.63	1.75	2.29	1.71	1.09	1.67	1.19
TIO2	0.03	0.02	0.00	0.01	0.00	0.00	0.01	0.00	0.03	0.04	0.00	0.04
MNO	0.50	1.48	1.62	1.39	1.39	1.48	1.36	1.32	1.40	0.74	0.91	0.55
CR2O3	0.08	0.07	0.00	0.04	0.02	0.03	0.03	0.03	0.01	0.03	0.04	0.18
TOTAL	100.15	101.77	100.05	100.69	100.72	101.37	101.04	101.63	101.46	101.47	99.78	100.82
CATIONS PER 12 OXYGENS												
SI	2.981	2.997	3.005	2.963	2.978	2.964	2.978	2.967	2.991	2.997	2.965	2.981
AL	2.025	1.976	1.999	2.010	1.999	2.015	2.014	2.016	2.011	1.985	2.013	1.997
FE	1.758	2.154	2.164	2.153	2.250	2.265	2.202	2.183	2.239	2.310	2.162	2.038
MG	0.967	0.595	0.563	0.617	0.564	0.534	0.573	0.570	0.519	0.560	0.673	0.833
CA	0.228	0.178	0.153	0.173	0.127	0.136	0.147	0.190	0.143	0.090	0.140	0.098
TI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.002
MN	0.031	0.096	0.107	0.092	0.093	0.097	0.090	0.087	0.092	0.048	0.061	0.034
CR	0.004	0.002	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.009
TOTAL	7.994	7.998	7.991	8.010	8.011	8.011	8.004	8.013	7.995	7.992	8.016	7.992

1/ Xenocryst in alnoite, Bird Rapids 2 diatreme, NE1/4 SW1/4 sec. 17, T. 23N., R. 20E., field no. H67-20E.

2/ Garnet-biotite-plagioclase-apatite-rutile sillimanite schist inclusion in Ervin Ridge 1 diatreme, SE1/4 SW1/4 sec. 26, T. 24N., R. 20E., field no. P64-10B.

3/ Garnet-kyanite-muscovite-K feldspar-quartz schist, Precambrian basement, Little Rocky Mountains, 6.5 km north of Zortman, NE1/4 SW1/4 sec. 29, T. 26N., R. 25E., field no. P63-11B.

4/ Garnet from pebbles of mica schist (Precambrian) in conglomeratic sandstone of Fort Union Formation (Paleocene) in large inclusion down-faulted into Squaw Creek diatreme, SW1/4 NE1/4 sec. 29, T. 25N., R. 22E., field no. P65-19I.

5/ Garnet in conglomeratic sandstone of Fort Union Formation (Paleocene) in large inclusion down-faulted into Shellenberger Divide diatreme, SE1/4 SW1/4 sec. 21, T. 24N., R. 22E., field no. P65-23A.

6/ Garnets from anthill on Thorsen dike, probably residual grains from erosion of nearby terrace gravel deposits derived from Little Rocky Mountains, NW1/4 SE1/4 NW1/4 sec. 28, T. 25N., R. 23E., field no. P64-41A-2.

Figure Captions

Figure 1.--Geologic map of Williams diatremes, north-central Montana.

Figure 2.--Ca-Mg-Fe diagrams for colluvial garnets, Williams diatremes.

A, Red-orange, orange, and light-orange garnets. B, Purple, red, and pink garnets. C, Megacrysts, garnets from garnet peridotites, mafic granulites, mafic amphibolites, and other inclusions.

Figure 3.--Histograms showing wt. percent Cr_2O_3 content of periditite and colluvial garnets by color groups, Williams diatremes.

Figure 4.-- Wt percent CaO vs. wt percent Cr_2O_3 diagrams, Williams diattremes. A, Colluvial garnets with Cr_2O_3 greater than 0.50 wt percent. B, Megacryst garnets and garnets from garnet peridotites.

Figure 5.--Cr vs. Mg/(Mg + Fe) diagrams, Williams diatremes. A, Colluvial garnets. B, Garnets from inclusions and megacrysts.

Figure 6.-- Cr vs. Al diagrams, Williams diatremes. A, Purple, pink, and red colluvial garnets. B, Garnets in peridotites and megacrysts.

Figure 7.--Ca-Mg-Fe diagrams, other localities. A, Alluvial and inclusion garnets, Bullwhacker Coulee diatreme. B, Alluvial and inclusion garnets, Big Slide diatreme. C, Garnets from miscellaneous localities.

Figure 8.--Cr vs. Mg/(Mg + Fe) diagrams, other localities. A, Alluvial and inclusion garnets, Bullwhacker Coulee diatreme. B, Alluvial and inclusion garnets, Big Slide diatreme. C, Garnets from miscellaneous localities.

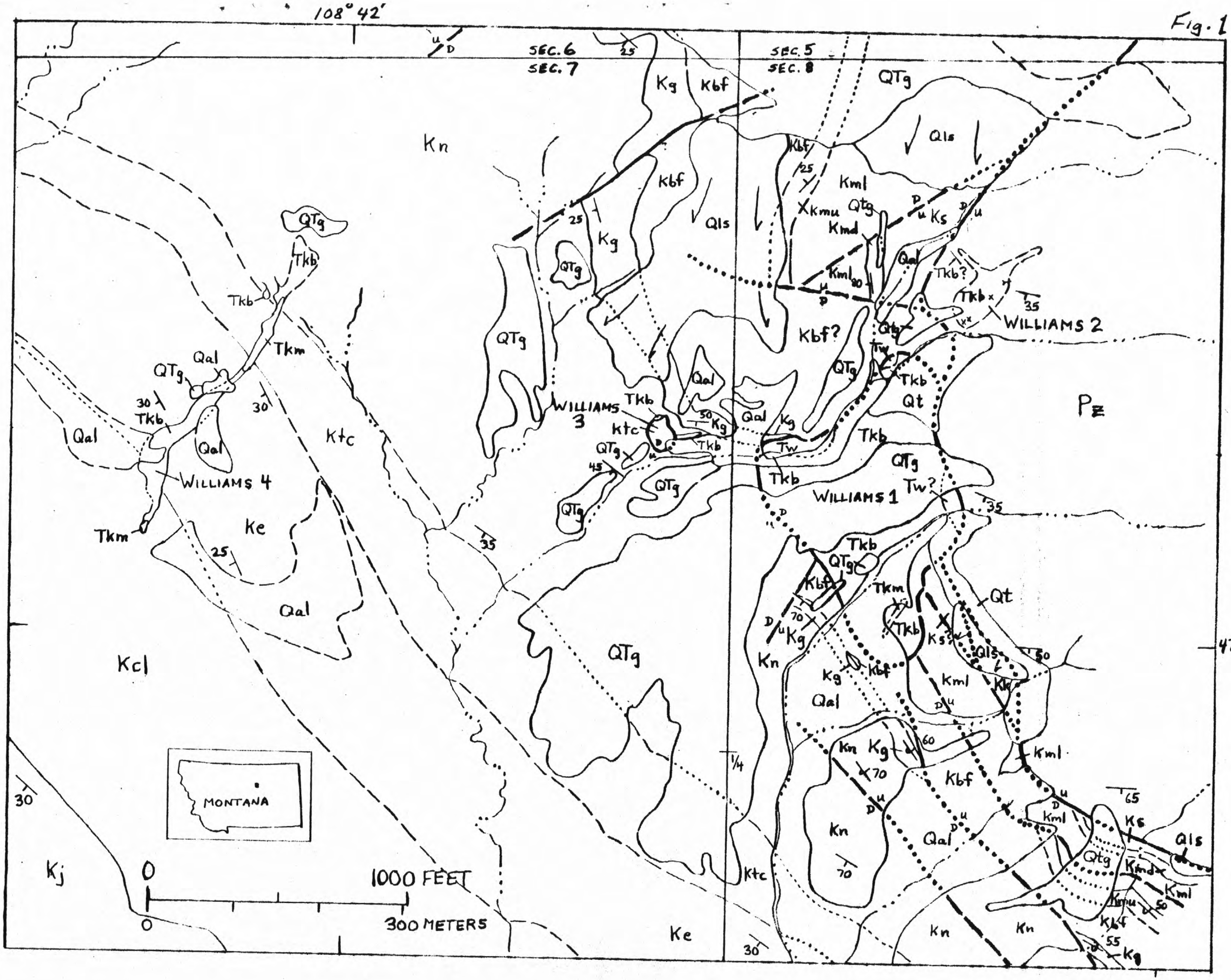

108° 42'
SEC. 6
SEC. 7
SEC. 5
SEC. 8
47°51'
Kn
Kg
Kbf
QTg
Qls
Kml
Kmu
Kmd
Ks
Qal
Tkb
Tkb?
Tkm
Ktc
Ke
Kcl
Kj
Qt
Tw
Tw?
Kbf?
Pz
WILLIAMS 1
WILLIAMS 2
WILLIAMS 3
WILLIAMS 4
MONTANA
0
1000 FEET
0
300 METERS

Fig. 1

Figure 1: EXPLANATION

Qal	Alluvial and colluvial deposits	Holocene and Pleistocene	QUATERNARY
Qls	Landslide deposits		
Qt	Talus deposits		
QTg	Terrace and pediment gravel deposits	Pleistocene and Pliocene?	
Tkm	Massive kimberlite	Middle Eocene	TERTIARY
Tkb	Kimberlite breccia		
Tw	Wasatch Formation	Lower Eocene	
Kj	Judith River Formation	Upper Cretaceous	CRETACEOUS
Kcl	Claggett Shale		
Ke	Eagle Sandstone		
Ktc	Telegraph Creek Formation		
Kn	Niobrara Formation and Carlile Shale		
Kg	Greenhorn Formation and Mosby Sandstone Member of Belle Fourche Shale		
Kbf	Belle Fourche Shale		
Kmu	Mowry Shale, upper member	Lower Cretaceous	
Kml	Mowry Shale, lower member		
Kmd	Muddy Sandstone		
Ks	Skull Creek Shale		
Kk	Kootenai Formation		
Pz	Paleozoic, undivided	Lower Miss. to Cambrian	PALEOZOIC

	Contact, dashed where approximately located, dotted where concealed
U D	Fault, dashed where approximately located, dotted where concealed; U, upthrown side; D, downthrown side
30 70	Strike and dip of inclined, vertical and overturned beds
	Prospect pit
	Adit
	Arrows indicate direction of landslide movement

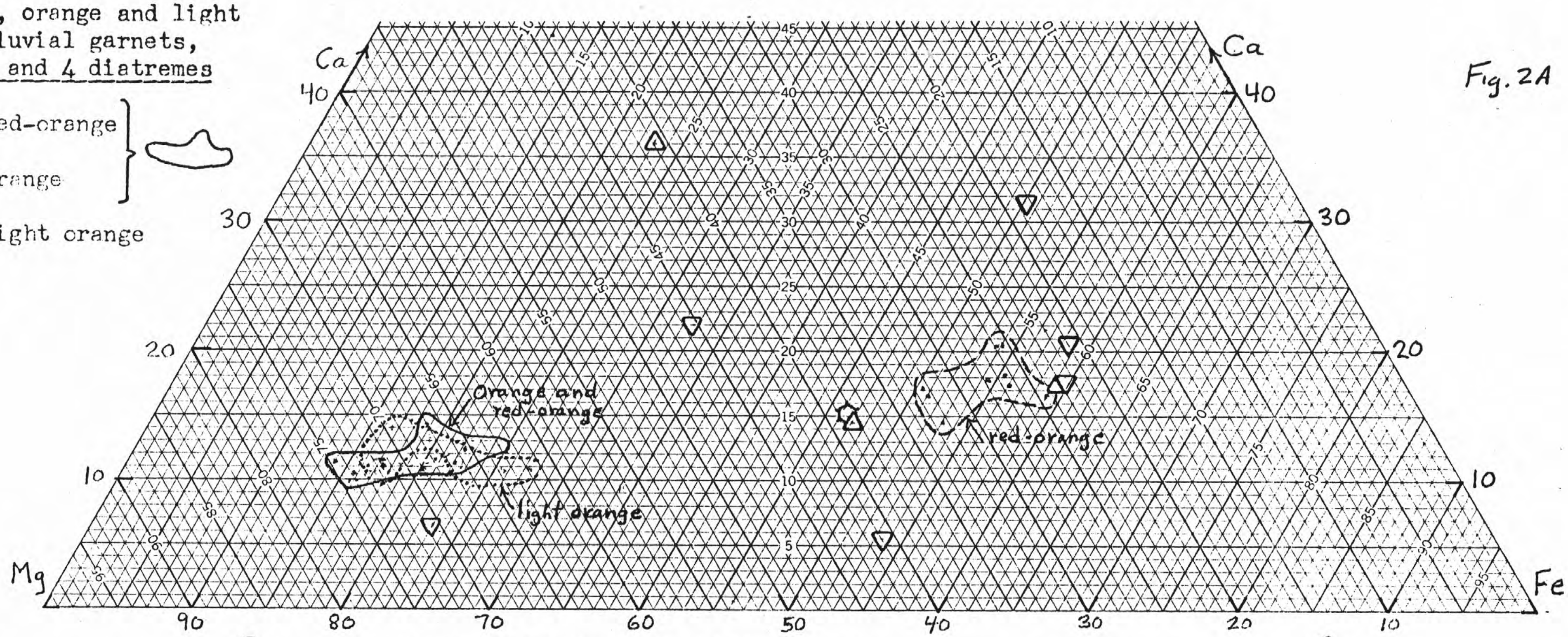
ed-orange, orange and light
range colluvial garnets,
illiams 1 and 4 diatremes

Red-orange

Orange

Light orange

Fig. 2A



nlarged plot of red-
range, orange and light
range Mg-rich colluvial
arnets

Red-orange
Orange
Light orange

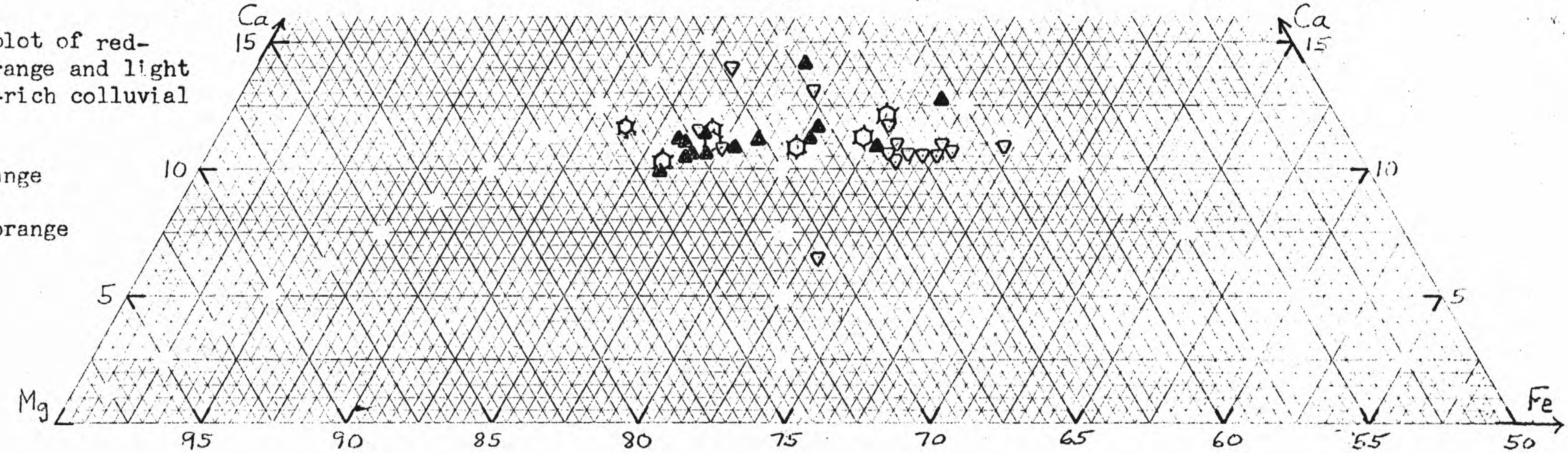


Fig. 2B

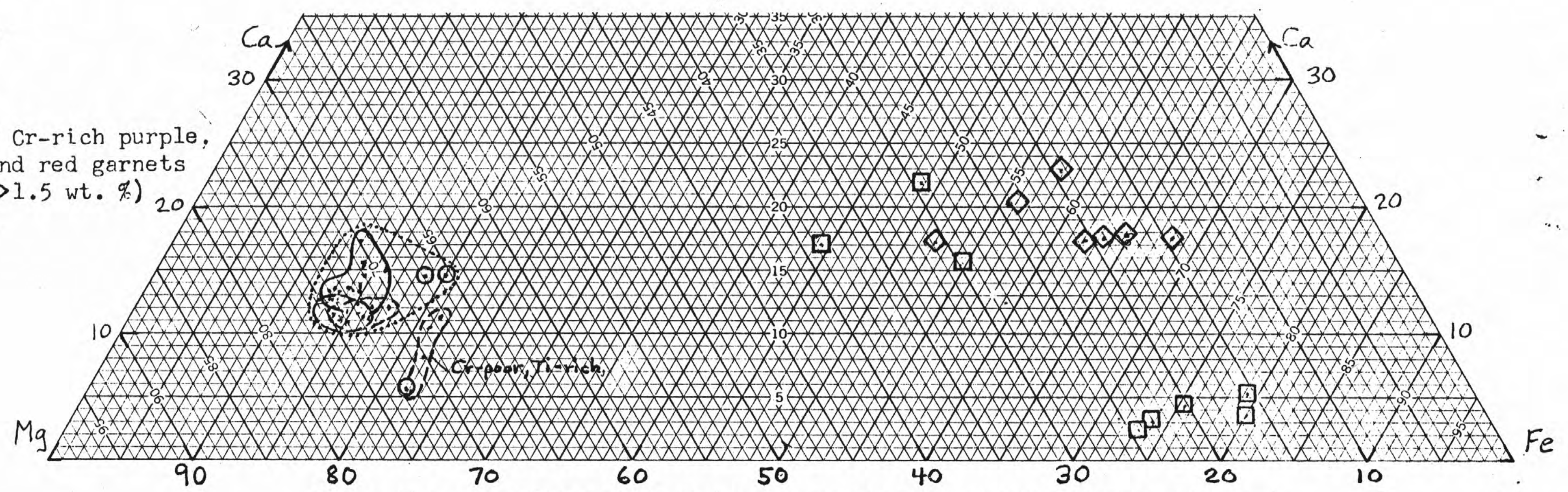
Purple, pink and red colluvial garnets, Williams 1 and 4 diatremes

O Purple

□ Pink

◇ Red

Area of Cr-rich purple, pink, and red garnets (Cr_2O_3 >1.5 wt. %)



Enlarged plot of purple, pink and red Mg-rich colluvial garnets; and areas of peridotite garnets

Colluvial:

O Purple

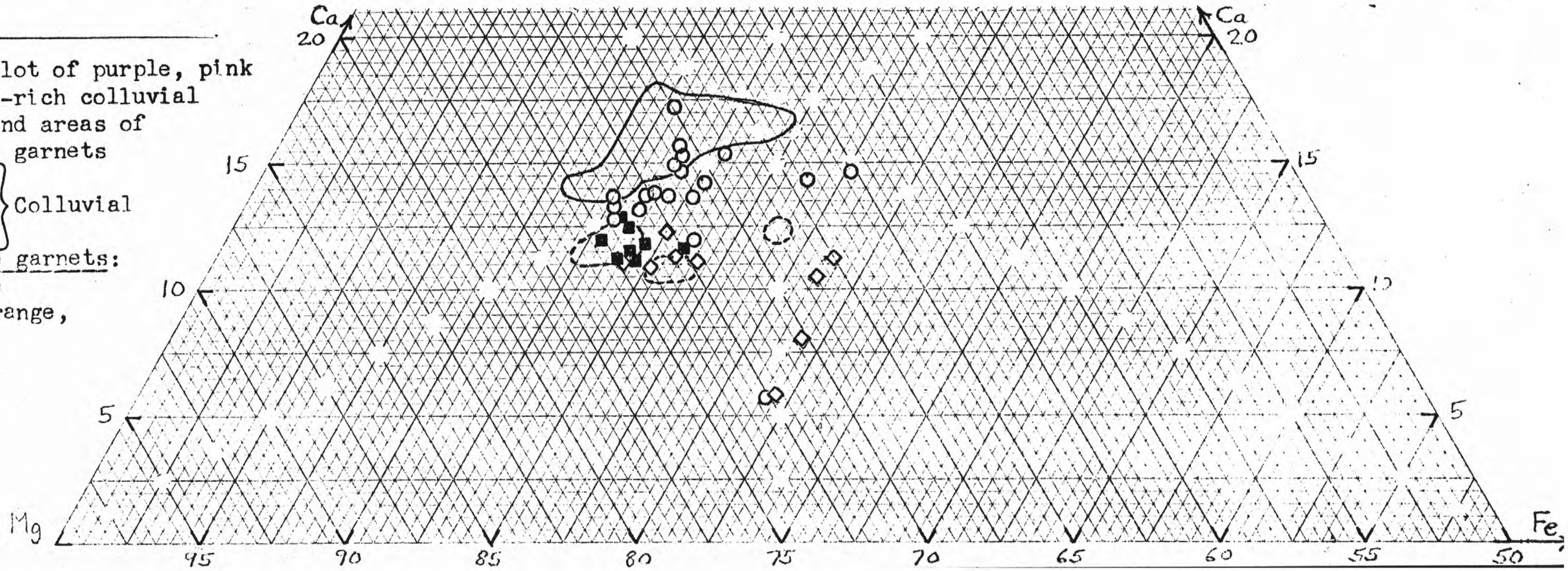
■ Pink

◇ Red

Peridotite garnets:

Purple

Red-orange, Red



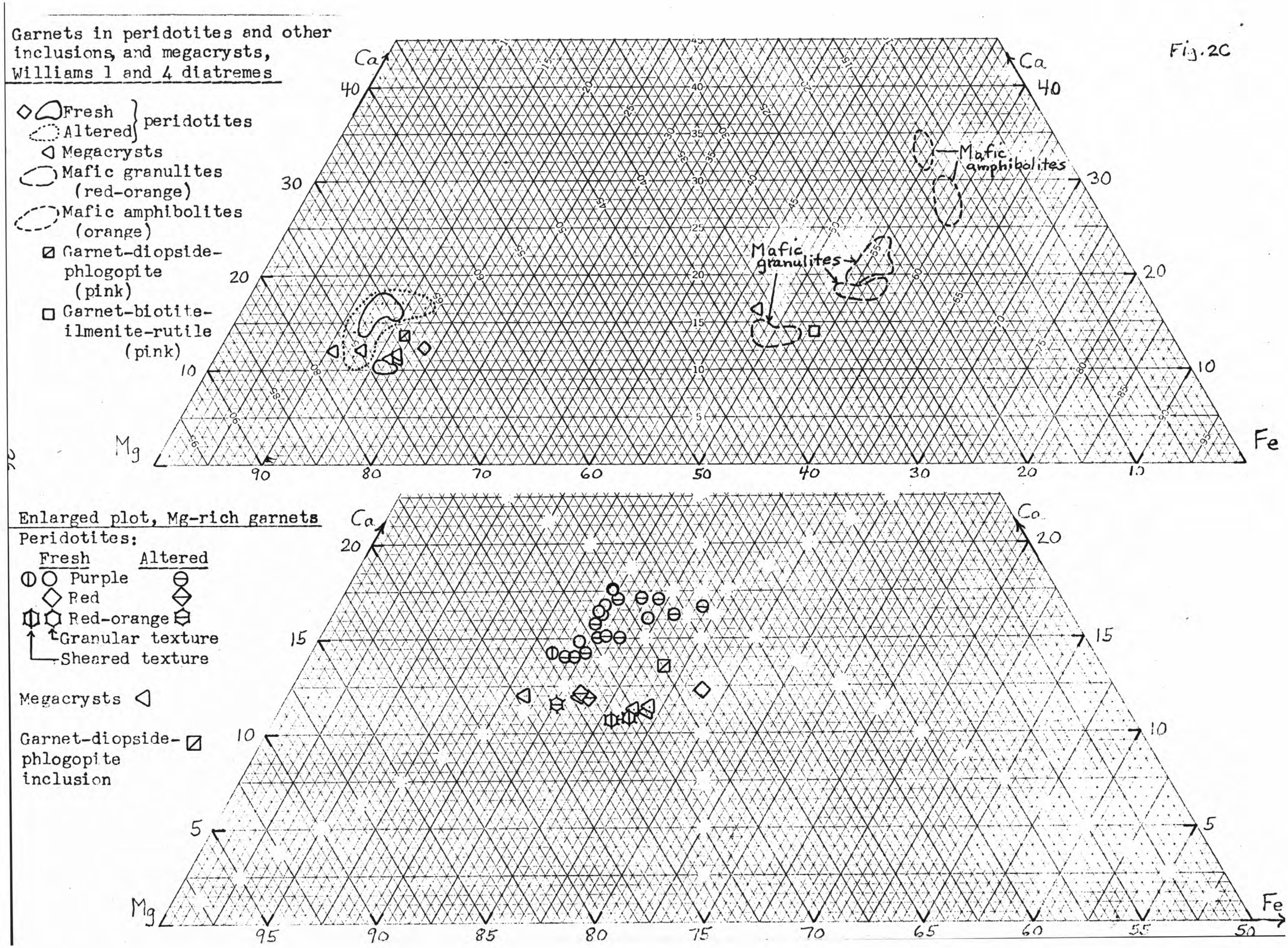
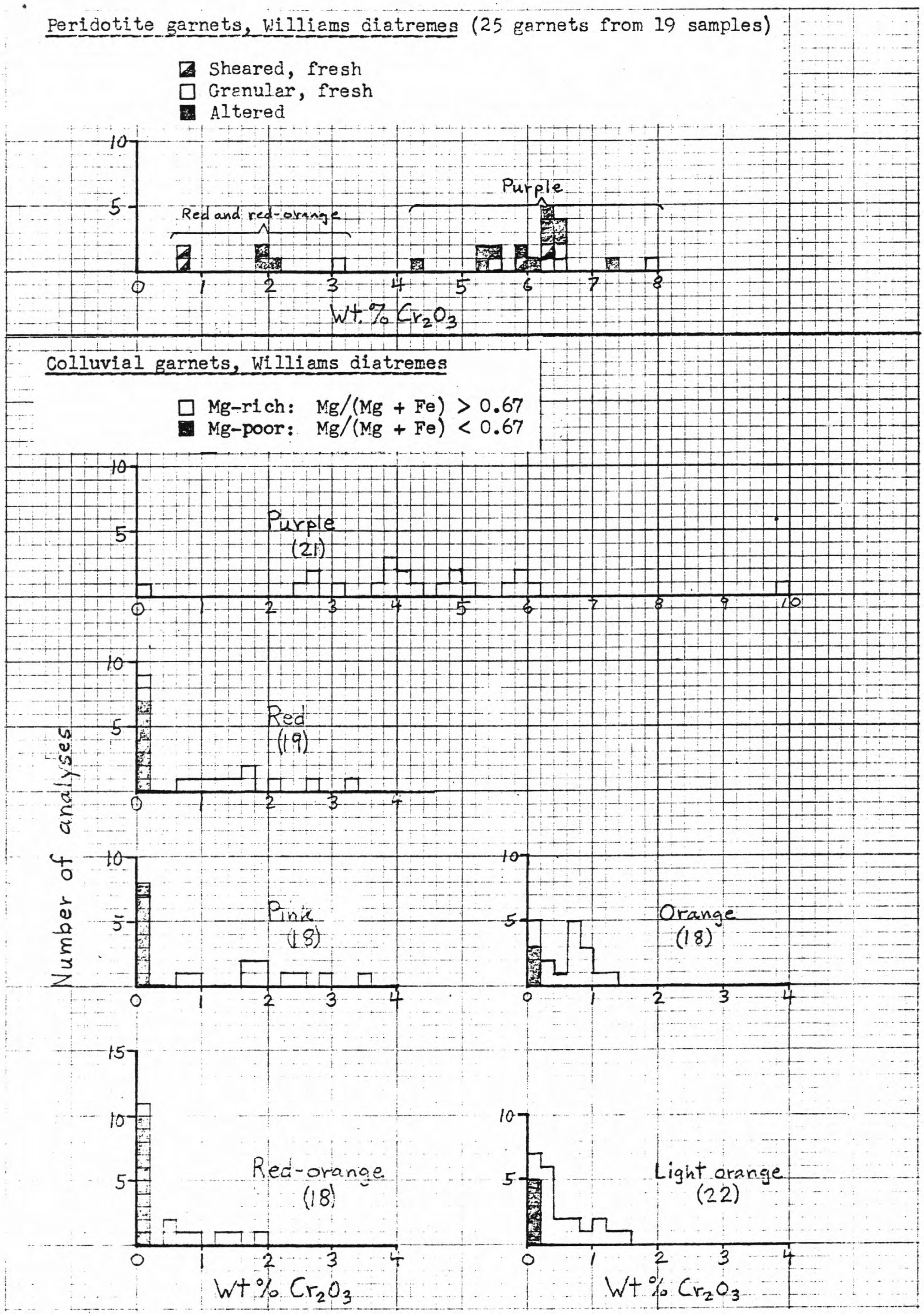
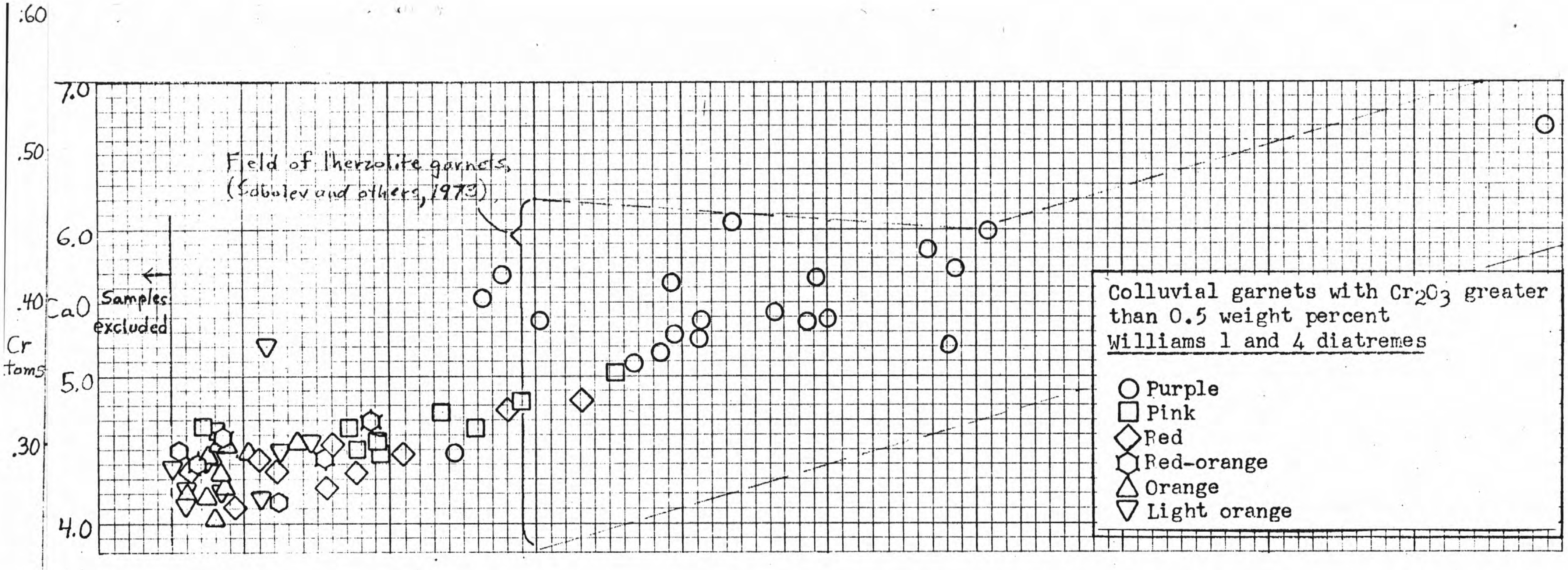

Garnets in peridotites and other inclusions, and megacrysts, Williams 1 and 4 diatremes
Fresh
Altered
peridotites
Megacrysts
Mafic granulites (red-orange)
Mafic amphibolites (orange)
Garnet-diopside-phlogopite (pink)
Garnet-biotite-ilmenite-rutile (pink)
Fig. 2C
Ca
Mg
Fe
Mafic amphibolites
Mafic granulites
Enlarged plot, Mg-rich garnets
Peridotites:
Fresh
Altered
Purple
Red
Red-orange
Granular texture
Sheared texture
Megacrysts
Garnet-diopside-phlogopite inclusion

Fig. 3

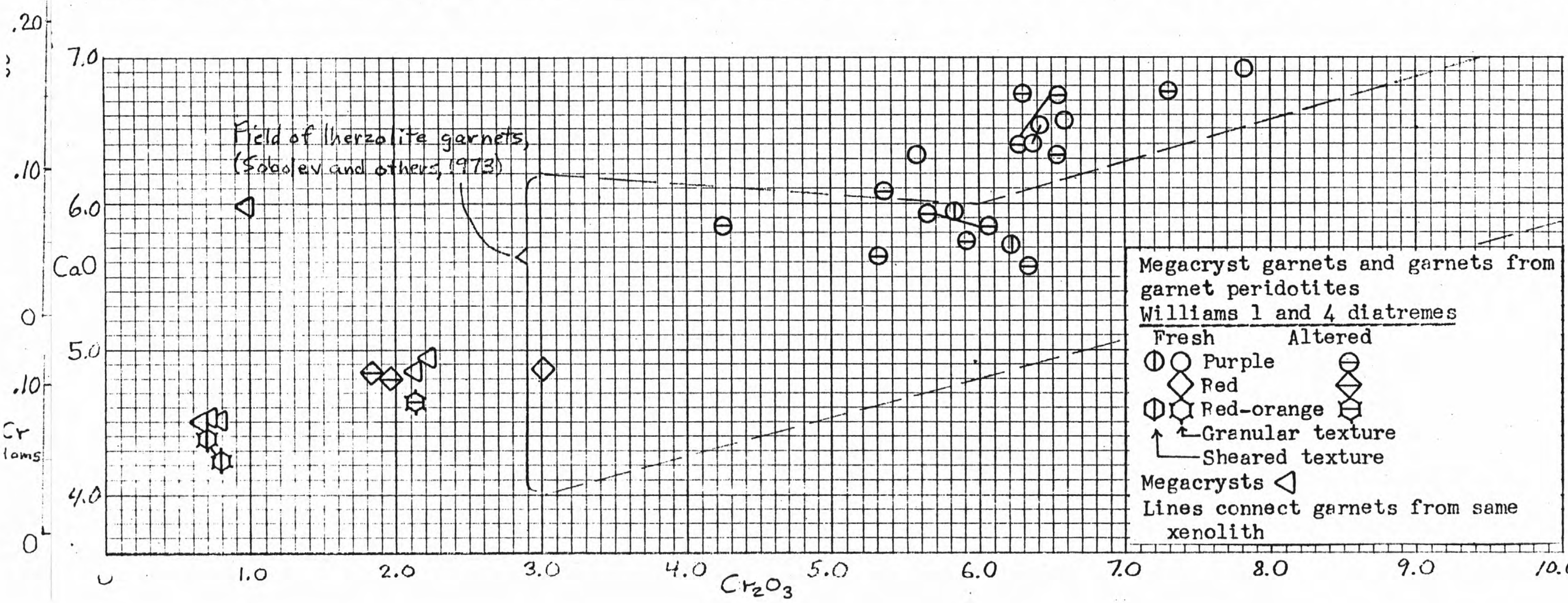


Peridotite garnets, Williams diatremes (25 garnets from 19 samples)
Sheared, fresh
Granular, fresh
Altered
Red and red-orange
Purple
Wt. % Cr2O3
Colluvial garnets, Williams diatremes
Mg-rich: Mg/(Mg + Fe) > 0.67
Mg-poor: Mg/(Mg + Fe) < 0.67
Purple (21)
Red (19)
Pink (18)
Orange (18)
Red-orange (18)
Light orange (22)
Number of analyses
Wt % Cr2O3
Wt % Cr2O3



.60
.50
.40
.30
.20
Cr atoms
7.0
6.0
5.0
4.0
CaO
Samples excluded
Field of lherzolite garnets, (Sobolev and others, 1973)
Colluvial garnets with Cr2O3 greater than 0.5 weight percent
Williams 1 and 4 diatremes
Purple
Pink
Red
Red-orange
Orange
Light orange

Fig 4A



.10
0
.10
0
Cr atoms
7.0
6.0
5.0
4.0
CaO
Field of lherzolite garnets, (Sobolev and others, 1973)
Megacryst garnets and garnets from garnet peridotites
Williams 1 and 4 diatremes
Fresh
Altered
Purple
Red
Red-orange
Granular texture
Sheared texture
Megacrysts
Lines connect garnets from same xenolith
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Cr2O3

Fig 4B

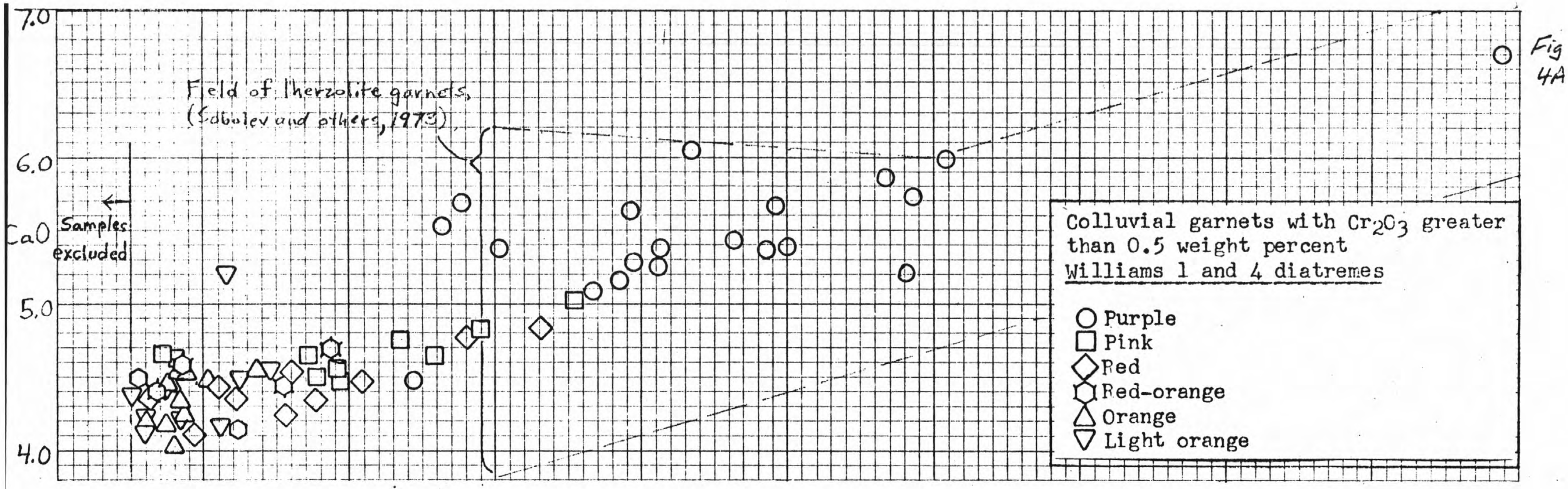


Fig 4A
7.0
6.0
5.0
4.0
CaO
Samples excluded
Field of lherzolite garnets, (Sobolev and others, 1973)
Colluvial garnets with Cr_2O_3 greater than 0.5 weight percent
Williams 1 and 4 diatremes
Purple
Pink
Red
Red-orange
Orange
Light orange

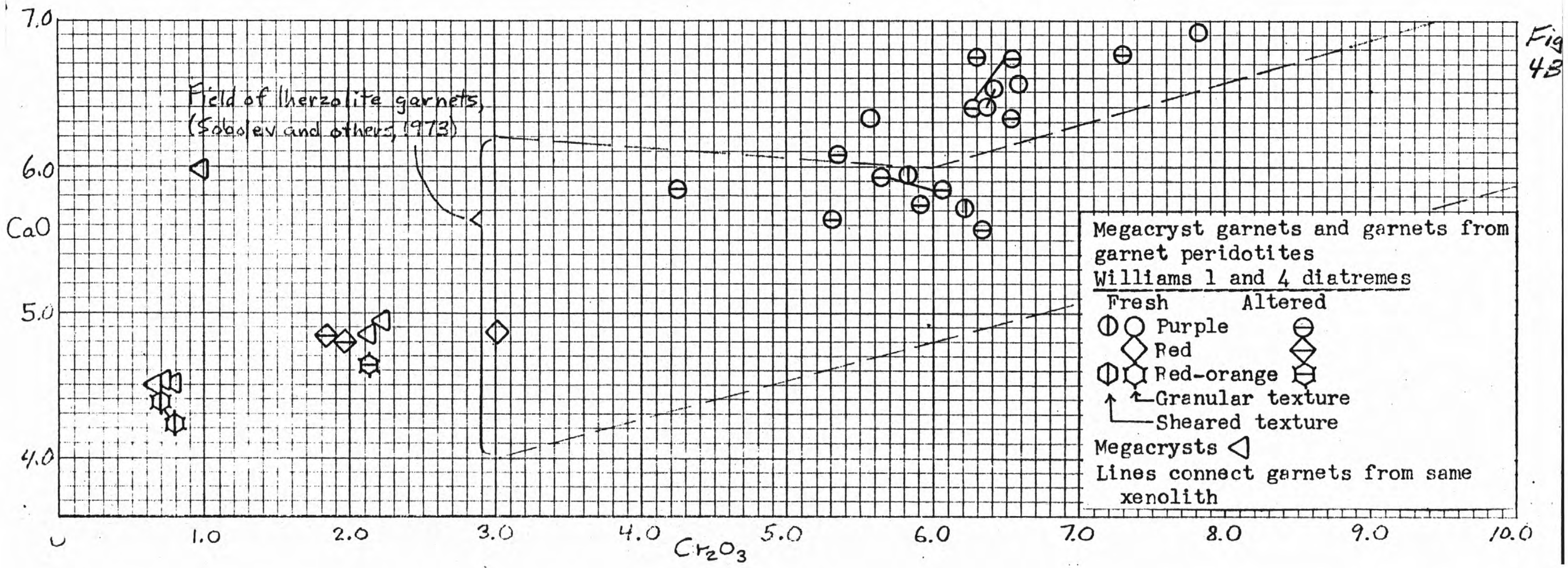
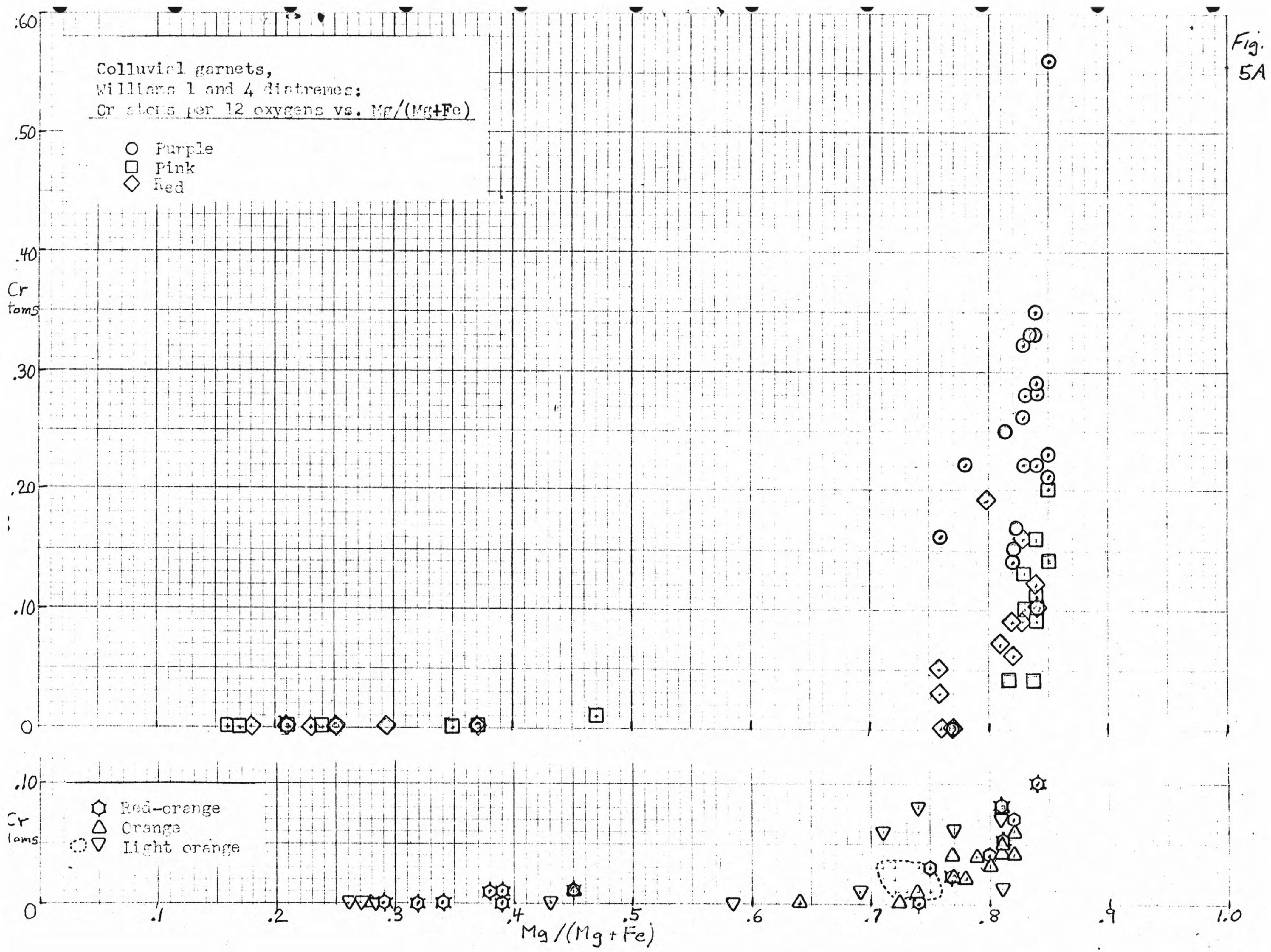


Fig 4B
7.0
6.0
5.0
4.0
CaO
Field of lherzolite garnets, (Sobolev and others, 1973)
Megacryst garnets and garnets from garnet peridotites
Williams 1 and 4 diatremes
Fresh
Altered
Purple
Red
Red-orange
Granular texture
Sheared texture
Megacrysts
Lines connect garnets from same xenolith
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Cr_2O_3



Colluvial garnets,
Williams 1 and 4 diatremes:
Cr atoms per 12 oxygens vs. Mg/(Mg+Fe)
Purple
Pink
Red
Red-orange
Orange
Light orange
Cr
atoms
Mg/(Mg+Fe)
.60
.50
.40
.30
.20
.10
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

Fig. 5A

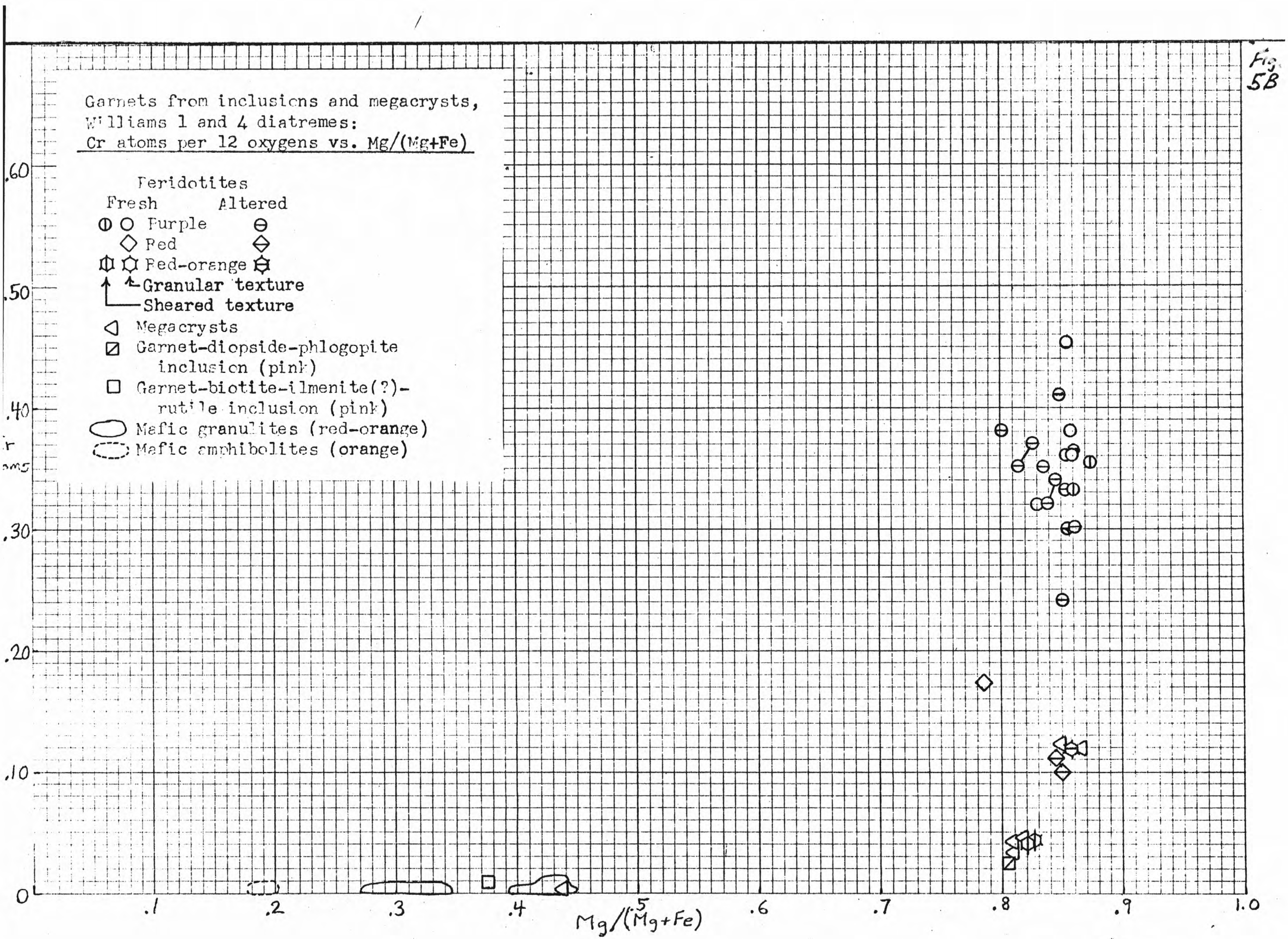
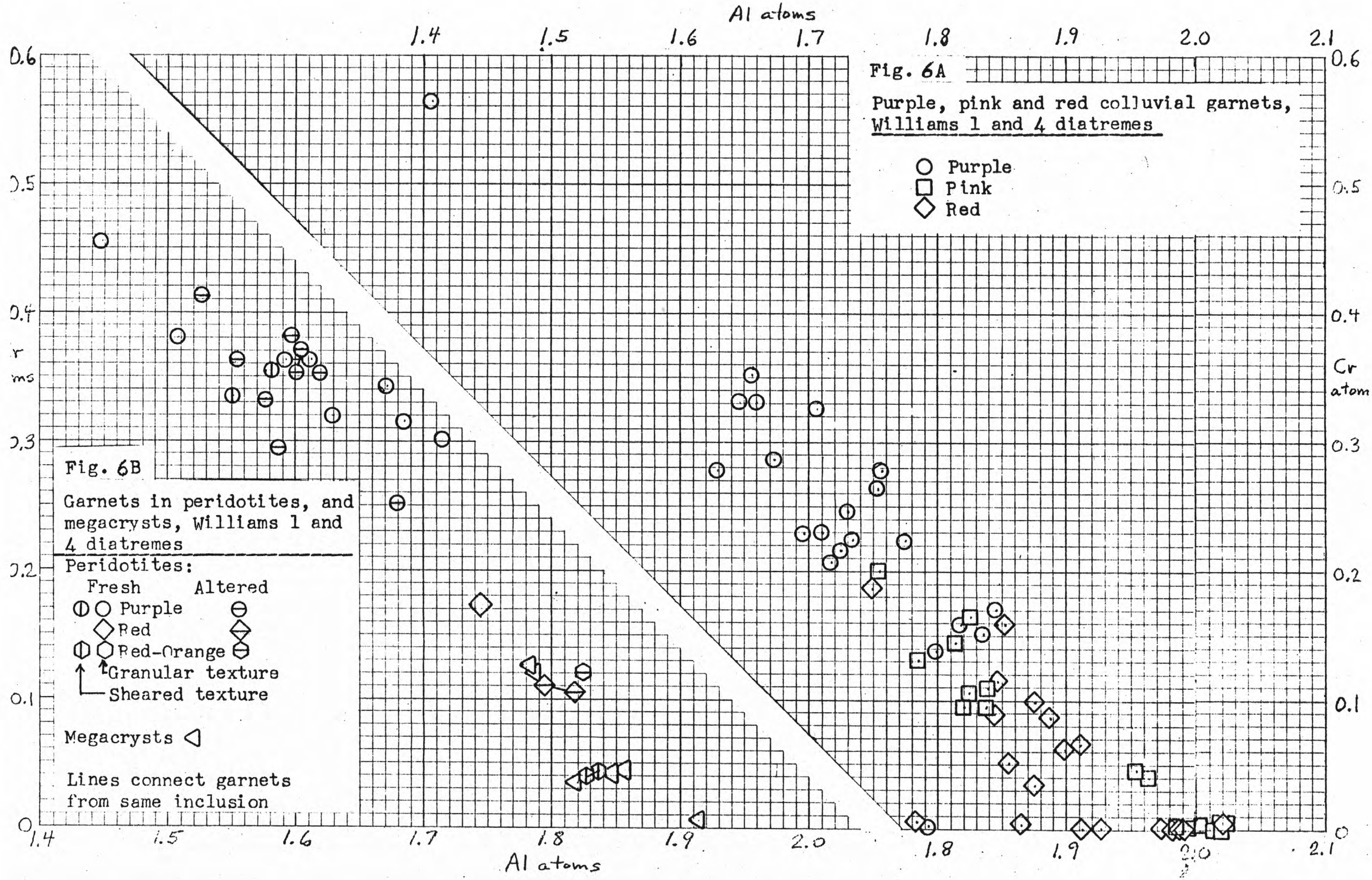

Garnets from inclusions and megacrysts,
Williams 1 and 4 diatremes:
Cr atoms per 12 oxygens vs. Mg/(Mg+Fe)
Peridotites
Fresh
Altered
Purple
Red
Red-orange
Granular texture
Sheared texture
Megacrysts
Garnet-diopside-phlogopite inclusion (pink)
Garnet-biotite-ilmenite(?)-rutile inclusion (pink)
Mafic granulites (red-orange)
Mafic amphibolites (orange)
.60
.50
.40
.30
.20
.10
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Mg/(Mg+Fe)

Fig. 5B



Al atoms
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
0.6
0.5
0.4
0.3
0.2
0.1
0
Cr atom
Fig. 6A
Purple, pink and red colluvial garnets, Williams 1 and 4 diatremes
Purple
Pink
Red
Fig. 6B
Garnets in peridotites, and megacrysts, Williams 1 and 4 diatremes
Peridotites:
Fresh
Altered
Purple
Red
Red-Orange
Granular texture
Sheared texture
Megacrysts
Lines connect garnets from same inclusion

Garnets, Bullwhacker Coulee diatreme

- Phlogopite orthopyroxenite(?) (pink)
- Amphibole-diopside orthopyroxenite(?) (pink)

Pan concentrate
- □ Pink
- △ Orange
- ▽ Light orange

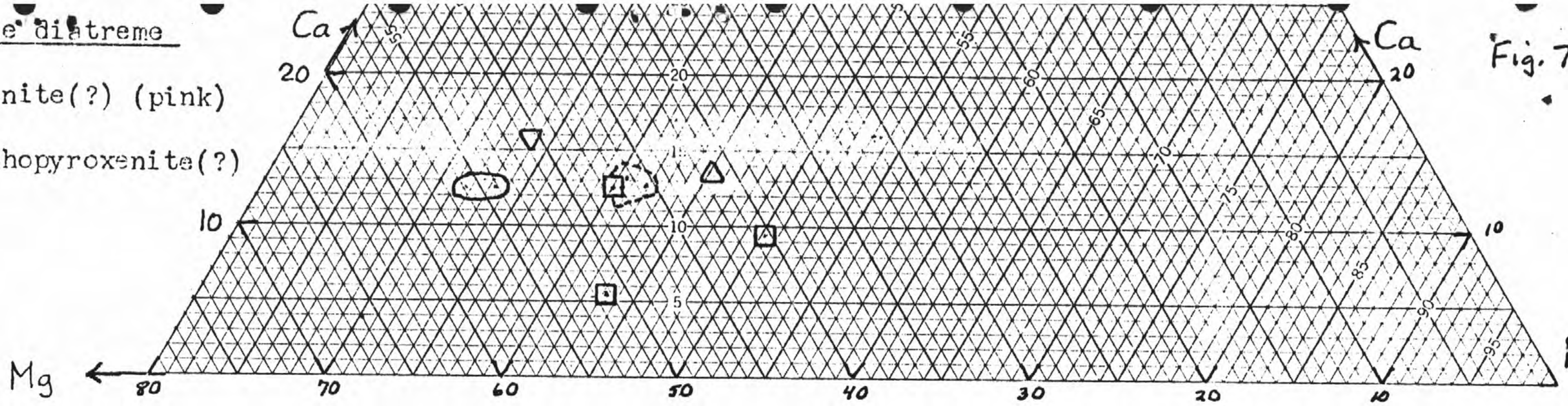


Fig. 7A

Alluvial and inclusion garnets, Big Slide 1 diatreme

- Garnet-kyanite granulitic gneiss (pink)

Pan concentrate
- ○ Purple
- □ Pink
- ◇ Red
- ✡ Red-orange
- △ Orange

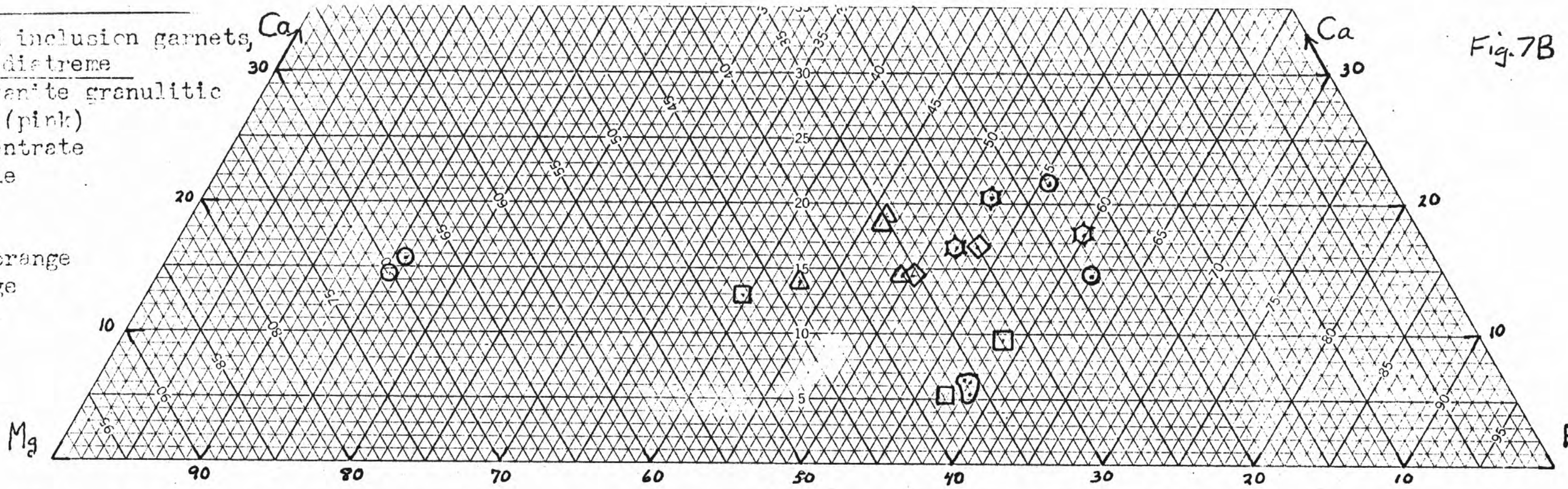


Fig. 7B

Garnets from other diatremes and Precambrian bedrock sources

- □ Xenocryst, Bird Rapids 2 diatreme (pink)
- Garnet-biotite-plagioclase-sillimanite schist inclusion in Ervin Ridge 1 diatreme (pink)
- Garnet-kyanite-muscovite-feldspar-quartz schist, Precambrian bedrock, Little Rocky Mtns. (orange)
- ⧅ Garnet in schist pebbles in Fort Union Formation conglomerate, Squaw Creek diatreme (pink)
- ⧄ Garnet in Fort Union Formation conglomerate, Shellenberger Divide diatreme (pink)
- ○ Garnet from anthill on Thorsen dike, probably residual from Little Rocky Mtns. terrace gravel (purple)
- Field of garnets known or assumed to be from shallow Precambrian rocks

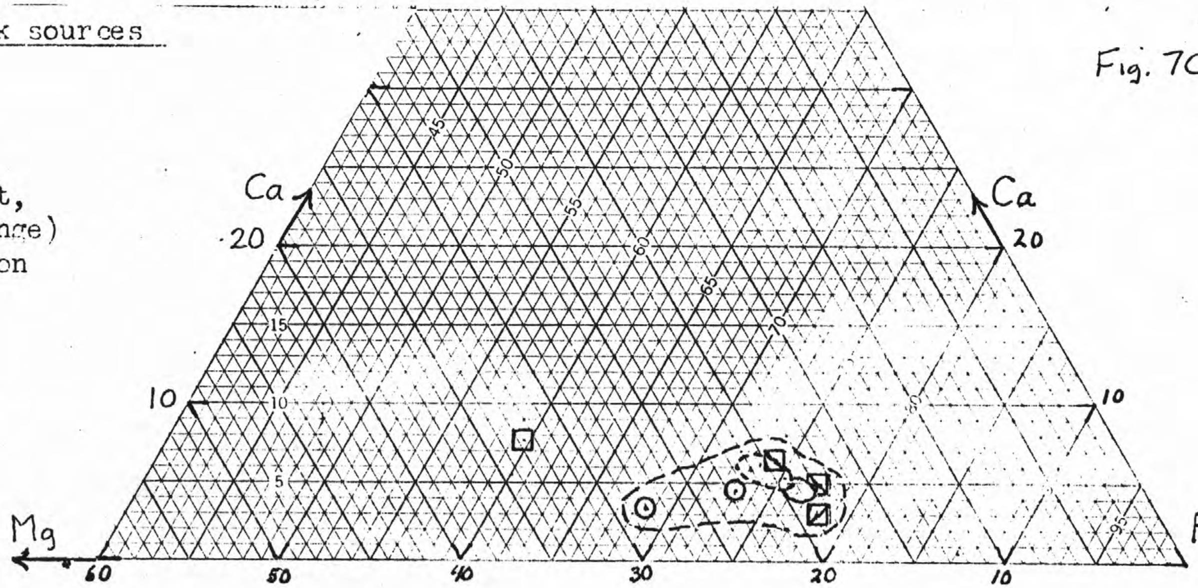


Fig. 7C

Fig. 8

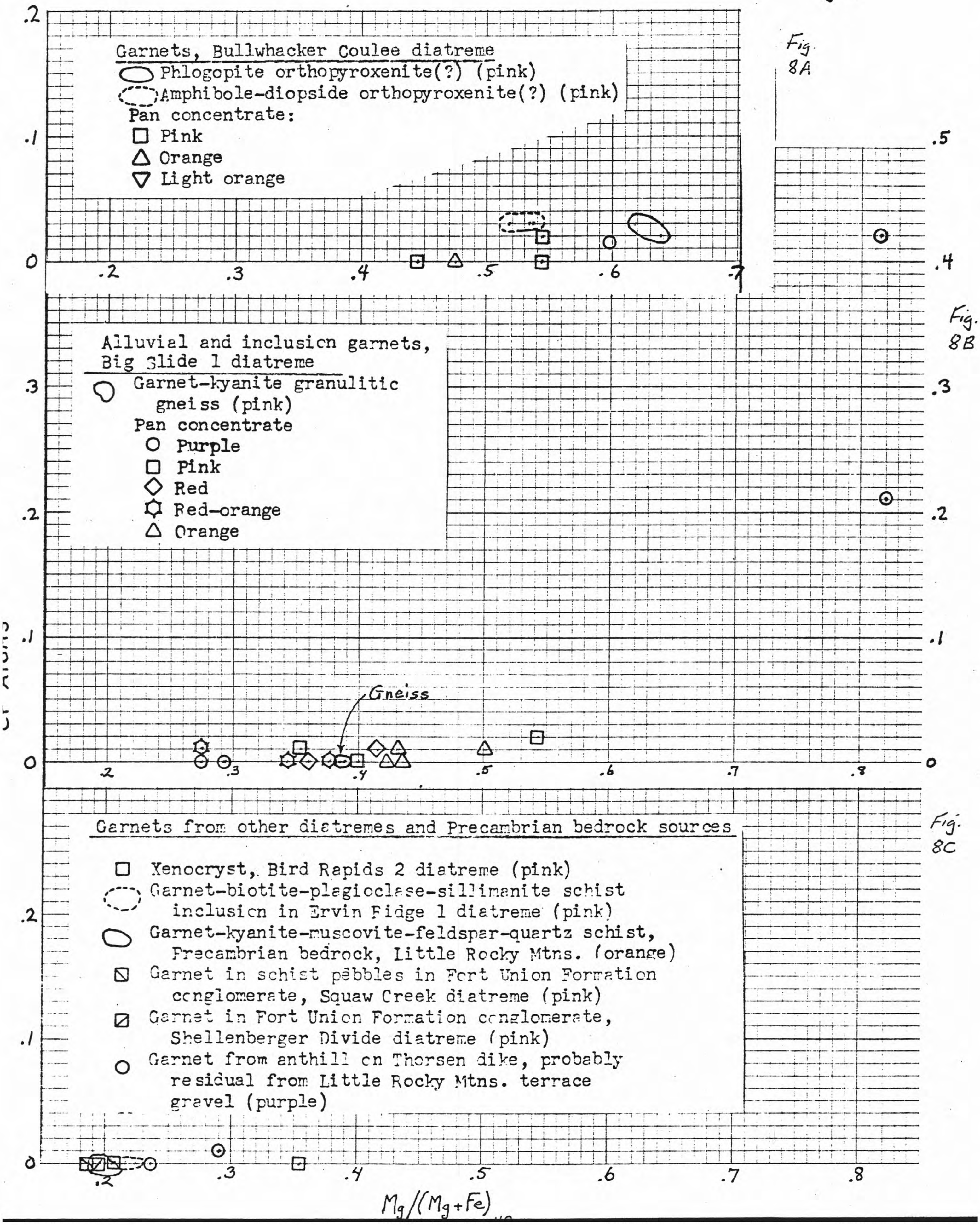


Fig. 8A
Garnets, Bullwhacker Coulee diatreme
Phlogopite orthopyroxenite(?) (pink)
Amphibole-diopside orthopyroxenite(?) (pink)
Pan concentrate:
Pink
Orange
Light orange
Fig. 8B
Alluvial and inclusion garnets, Big Slide 1 diatreme
Garnet-kyanite granulitic gneiss (pink)
Pan concentrate
Purple
Pink
Red
Red-orange
Orange
Gneiss
Fig. 8C
Garnets from other diatremes and Precambrian bedrock sources
Xenocryst, Bird Rapids 2 diatreme (pink)
Garnet-biotite-plagioclase-sillimanite schist inclusion in Ervin Ridge 1 diatreme (pink)
Garnet-kyanite-muscovite-feldspar-quartz schist, Precambrian bedrock, Little Rocky Mtns. (orange)
Garnet in schist pebbles in Fort Union Formation conglomerate, Squaw Creek diatreme (pink)
Garnet in Fort Union Formation conglomerate, Shellenberger Divide diatreme (pink)
Garnet from anthill on Thorsen dike, probably residual from Little Rocky Mtns. terrace gravel (purple)
Mg/(Mg+Fe)