THE EFFECT OF GRAIN SIZE ON DETRITAL MODES: A TEST OF THE GAZZI-DICKINSON POINT-COUNTING METHOD[1]

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ABSTRACT: Differing methods of determining detrital modes of sand/sandstone have been developed by different "schools" due to different goals and different geologic settings. The Gazzi-Dickinson method of point counting was developed to maximize source-rock data, while minimizing the time, effort, and expense of gathering such data. Use of the method minimizes variation of composition with grain size, thus eliminating the need for sieving and multiple counts of different size fractions. Unsorted samples of any sand size may be used, thus allowing direct comparison between modern sands and poorly sorted ancient sandstones. The application of actualistic petrologic models relating composition to tectonic setting thus is facilitated.

The unique aspect of the Gazzi-Dickinson method of point counting is the assignment of sand-sized crystals and grains within larger fragments to the category of the crystal or grain, rather than to the category of the larger fragment. In addition, every attempt is made to reconstruct original detrital compositions in spite of subsequent alterations.

Six unconsolidated Holocene sand samples derived from a variety of source rocks in north-central New Mexico were collected, sieved, impregnated, sectioned, stained and point-counted, using both traditional and Gazzi-Dickinson methods. Results of these counts provide a comparative test of traditional and Gazzi-Dickinson methods.

There are two reasons for variation of modal composition with grain size: 1) the breakage of fragments into constituent grains, and 2) actual mineralogic variation with grain size. The Gazzi-Dickinson method successfully eliminates the first source of compositional grain-size dependency. No point-counting method eliminates the second source. Use of the Gazzi-Dickinson method on unsorted samples produces results that are consistent with those from different size fractions of the same samples. Lithic-fragment compositions (for example, LmLvLs, QpLvmLsm) are especially consistent and provide the most useful parameters for relating composition to source rock and, ultimately, to tectonic setting.

INTRODUCTION

Compositions of detrital sediments are controlled by four factors: provenance, transportation, depositional environment, and diagenesis (Suttner 1974). An individual study of ancient sediments commonly has the goal of understanding one or more of these factors. Study of diagenesis commonly is most straightforward because it is the most recent process affecting a given sediment. On the other hand, reconstruction of provenance may be the most complicated because of subsequent modifications imposed by the other three factors. Reconstruction of provenance is most straightforward in situations where the other three factors have had minor effect. The provenance of a sediment includes all aspects of the source area, including source rocks, climate, and relief (Pettijohn et al. 1972). In areas of intense tectonic/magmatic activity, source-rock type determines sediment composition more than do climate and relief (Dickinson 1970). Where tectonism/magmatism is absent, climate and relief are more important in determining composition (Basu 1976). An additional complicating factor is that recycling of sediment may have a

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profound effect on compositions but commonly may be difficult to recognize or quantify (Blatt 1967).

Different "schools" of sedimentary petrology have evolved over the last several years which are in apparent competition and disagreement concerning which factors are the most important in determining sediment (primarily sand/sandstone) compositions. These apparent conflicts result from contrast in emphasis. Petrologists interested in diagenesis employ different techniques than do those interested in paleoclimates or source rocks. Those working in tectonically active areas can determine source rocks more easily, whereas comparative paleoclimates can be determined more easily where source rocks are constant and tectonic activity is mild. None of these schools of sedimentary petrology is better than another; each has developed techniques to maximize the type of information most desired. The present paper is a discussion of the relative merits of a point-counting method developed independently by Gazzi (1966) (discussed by Gazzi et al. 1973; Zuffa 1980) and Dickinson (1970) that attempts to maximize information regarding source rocks in tectonically active settings. Petrologists interested in paleoclimates, transport history, diagenesis, or other aspects of sand/sandstone composition will probably choose alternative methods.

Far too few data exist relating compositions of Holocene sand to known source rocks, climates, and tectonic settings (Blatt 1967; Suttner 1974). Such data are needed in order to develop actualistic petrologic models which can be applied to the interpretation of ancient sandstones, whether for paleoclimate or paleotectonic studies. Use of such models will lessen the use of ad hoc hypotheses to explain sandstone compositions (Blatt 1967). The present study is the first step in a project designed to study Holocene sand from a variety of known source rocks in north-central New Mexico. Samples were collected from arroyos where less than 10 km of transport had occurred, so that breakdown of fragments due to stream transport has been negligible (see, for example, Basu 1976). The methods used are designed to maximize the type of information useful in determining source rocks and to minimize the time, effort and expense in gathering data.

GRAIN SIZE AND MODAL COMPOSITION

The apparent dependence of sandstone detrital modes on grain size has been demonstrated by several workers (see, for example, Basu 1976; Blatt 1967; Mack and Suttner 1977; Young et al. 1975). However, there are two basic schools of thought concerning the subject: 1) that which believes that there is a fundamental dependence of modal composition on grain size (Basu 1976; Mack and Suttner 1977; Suttner 1974); and 2) that which believes that modal composition can be determined independently of grain size (Dickinson 1970; Gazzi 1966).

The former school believes that grain-size change is accompanied by compositional variation as original clasts are altered in size and mineralogy through chemical and physical weathering processes (Basu 1976; Mack and Suttner 1977; Suttner 1974). Polymineralic, coarsely crystalline grains are counted as lithic fragments. Through mechanical breakdown, the proportion of coarse-grained lithic fragments decreases as the constituent minerals increase in the finer grain sizes. The traditional view is that this is an obvious compositional dependence on grain size. Additionally, composition is considered to be a complex function of provenance, transportation history, depositional modification, and diagenesis (Suttner 1974).

Less traditional methods (Dickinson 1970; Gazzi 1966; Gazzi et al. 1973; Graham et al. 1976; Ingersoll 1978; Ingersoll and Suczek 1979) place greater emphasis on using petrographic techniques to reconstruct original detrital compositions independent of grain size. Dickinson (1970) argues that the identification and recording of mineral crystals of sand size, whether within coarse-grained lithic fragments or not, reduces compositional dependence on grain size. Additionally, careful petrographic techniques (applied by both schools of methodologists) allow the reconstruction of grains severely altered because of physical or chemical diagenetic effects. Thus, alterations such as those described by Walker et al. (1978) do not change detrital modes significantly. The Gazzi-Dickinson method reduces the effects of grain size and alteration on composition and thereby allows accurate determination of original detrital mode and provenance.

TABLE 1.—*Grain parameters (after Dickinson 1970; Graham et al. 1976; and Ingersoll and Suczek 1979)*

Counted parameters	Recalculated parameters
Qp = polycrystalline quartz (inc. chert)	Q = Qm + Qp
Qm = monocrystalline quartz	F = P + K
P = plagioclase feldspar	L = Lv + Lm + Ls + Lp
K = potassium feldspar	Lvm = Lv + xLm (where x ranges from 0 to 1 [operationally, usually 0])
Lv = volcanic-hypabyssal lithics	Lsm = Ls + (1 − x)Lm (operationally, Lsm usually equals Ls + Lm)
Lm = metamorphic lithics	Framework = Q + F + L + M + D + Misc.
Ls = sedimentary lithics	QFL%Q =100Q/(Q + F + L)
Lp = plutonic lithics (traditional method only)	QFL%F = 100F/(Q + F + L)
M = phyllosilicates	QFL%L = 100L/(Q + F + L)
D = dense minerals	Framework%M = 100M/Framework
Misc. = miscellaneous and unidentified	Framework%D = 100D/Framework
(x = fraction of metavolcanics in Lm [noted separately])	LmLvLs%Lm = 100Lm/(L − Lp) LmLvLs%Lv = 100Lv/(L − Lp)
	LmLvLs%Ls = 100Ls/(L − Lp)
	QpLvmLsm%Qp = 100Qp/(L − Lp + Qp)
	QpLvmLsm%Lvm = 100Lvm/(L − Lp + Qp)
	QpLvmLsm%Lsm = 100Lsm/(L − Lp + Qp)

The purpose of this study is to demonstrate the usefulness of the Gazzi-Dickinson method in determining the provenance of Holocene sands derived from contrasting source areas under constant climatic conditions. Because Holocene sands are generally unconsolidated, it is possible to separate grain-size classes and then to perform detailed petrographic studies on each size fraction. This study is also designed to show that, in most cases, the time required for accurate source-rock determinations can be reduced by eliminating point counts of individual grain-size classes. Data based on unsorted Holocene sand samples can be applied directly to the study of ancient sandstones of any grain size and degree of sorting.

SAMPLE COLLECTION AND PREPARATION

Six unconsolidated sand samples with known (and in some cases, mixed) provenance were collected for this study from arroyos in north-central New Mexico. The sands collected were derived from a wide variety of source rocks: metamorphic, plutonic, basaltic to felsic volcanic, and sedimentary. The samples were dried; disaggregated by hand, taking care not to break any grains; and split. One fraction of each split sample (Fraction 1) was saved as an unsieved representative. The remaining fraction was sieved at 1 ϕ intervals, resulting in five fractions. Fractions 2, 3, 4, 5, and 6 represent the intervals 4–3 ϕ, 3–2 ϕ, 2–1 ϕ, 1–0 ϕ, and 0–(−1) ϕ, respectively. The six fractions were poured into molds and impregnated with epoxy. The resulting artificial rocks were cut into standard thin sections and stained for plagioclase and potassium feldspars.

POINT-COUNTING METHODS

Each operator studied all six thin sections made from each sample. Parameters counted are described in Table 1; these parameters and criteria for their identification are described by Dickinson (1970), Graham et al. (1976), Ingersoll (1978), and Ingersoll and Suczek (1979). Matrix and cement were not counted (the unconsolidated sands contain little of either); grains finer than .03 mm (matrix) that remained in sieved fractions due to insufficient sieving were ignored in the counts. A few coarse silt grains (between .03 and .0625 mm) were counted in some sections.

For each thin section, each operator counted 300 points, using the maximum grid spacing that resulted in coverage of the entire slide. Because the sands are fresh and unaltered, identification of each grain was accomplished with certainty for almost all grains; therefore, 300 counts per section yielded statistically reliable values for all parameters (see, for example, Van der Plas and Tobi 1965). In other words, operator error does not contribute significantly to the variability of the results (see, for example, Ingersoll 1978). Some operators chose to make separate counts of each section (once using the traditional method and once using the Gazzi-Dickinson method), whereas other operators chose to use both counting methods simultaneously.

The primary way in which the Gazzi-Dickinson method differs from the traditional method is that monomineralic crystals and other grains of sand size (> .0625 mm) that occur within larger rock fragments are classified in the category of the crystal or other grain, rather than in the category of the larger rock fragment. Thus, plutonic rock fragments are counted as quartz, feldspar, mica, or whatever else is intersected by the cross hair. Other rock fragments containing sand-sized crystals in a fine-grained groundmass are counted as those crystals or as L, as determined by which part of the fragment is intersected. More rarely, a volcanic rock fragment of sand size within a larger sedimentary rock fragment would be classified as Lv rather than as Ls (see Table 1). There are two reasons for using this approach: 1) modal composition does not change due to simple breakage of grains (for example, weathering of granite produces quartz, feldspar, micas, and miscellaneous minerals no matter what the grain size of the sediment); and 2) counting of poorly sorted or coarse-grained sand or sandstone is faster because the operator does not have to determine in what kind of grain a sand-sized crystal occurs. This allows point counts to be completed at high magnification without frequent shifting to lower magnification to determine coarse lithic types. Also, diagenetically altered and squashed sandstones (including "graywackes") are treated more efficiently because all monocrystalline grains are treated similarly whether they occur as discrete grains or as phenocrysts or microphanerites. Separate note may be made of the relative percentages of discrete grains versus phenocrysts or microphanerites if this information is deemed useful. (Rarely does this type of information provide source-rock data that are not already known from the standard counts using this method.)

Use of the Gazzi-Dickinson method results in higher percentages of Q, F, M, and D, and lower L values than does the traditional method when counting coarse samples. Fine-grained samples show similar values using both methods. Also, the Gazzi-Dickinson parameters do not include a category for plutonic lithic fragments because such grains are counted as their constituent crystals. A few microphaneritic igneous fragments are included in the Lv category (volcanic and hypabyssal) if the part of the fragment counted contains crystals finer than sand. Fine-grained polycrystalline, microcrystalline, and cryptocrystalline quartz may be combined with monocrystalline quartz to make QFL% Q or with unstable lithic fragments to make QmFLt% Lt (total lithics) (Graham et al. 1976). The former method is followed here.

Only virtually pure silica is classified as Qp using the Gazzi-Dickinson method. The slightest amount of impurities within a chert grain results in this grain being classified as Ls; a single feldspar microcryst within a siliceous volcanic fragment makes it Lv; and a single flake of primary mica within a polycrystalline-quartz grain makes it Lm. This method differs from that of the Indiana "school" (for example, Basu 1976; Mack 1981; Mack and Suttner 1977; Suttner 1974; Suttner et al. 1981; Young et al. 1975); these workers use a ten-percent cutoff rather than a zero-percent cutoff. Using a ten-percent cutoff has the desirable effect of lessening variation of composition due to the presence of minor components. However, it has the undesirable effect of classifying individual crystals differently in different occurrences. For instance, using the Indiana method, a coarse-grained metamorphic fragment consisting of 91% monocrystalline quartz and 9% monocrystalline mica is classified as Qm no matter what part of the fragment is counted (G. H. Mack, personal communication, 1982). However, upon breakage of the quartz grain in half, the modal composition of the resulting fragments would become 50% Qm and 50% Lm (Lm would seemingly appear from nowhere). Using the Gazzi-Dickinson method, 91% of the time that the unbroken fragment is counted, it would be classified as Qm and 9% of the time, as Lm. Upon breakage

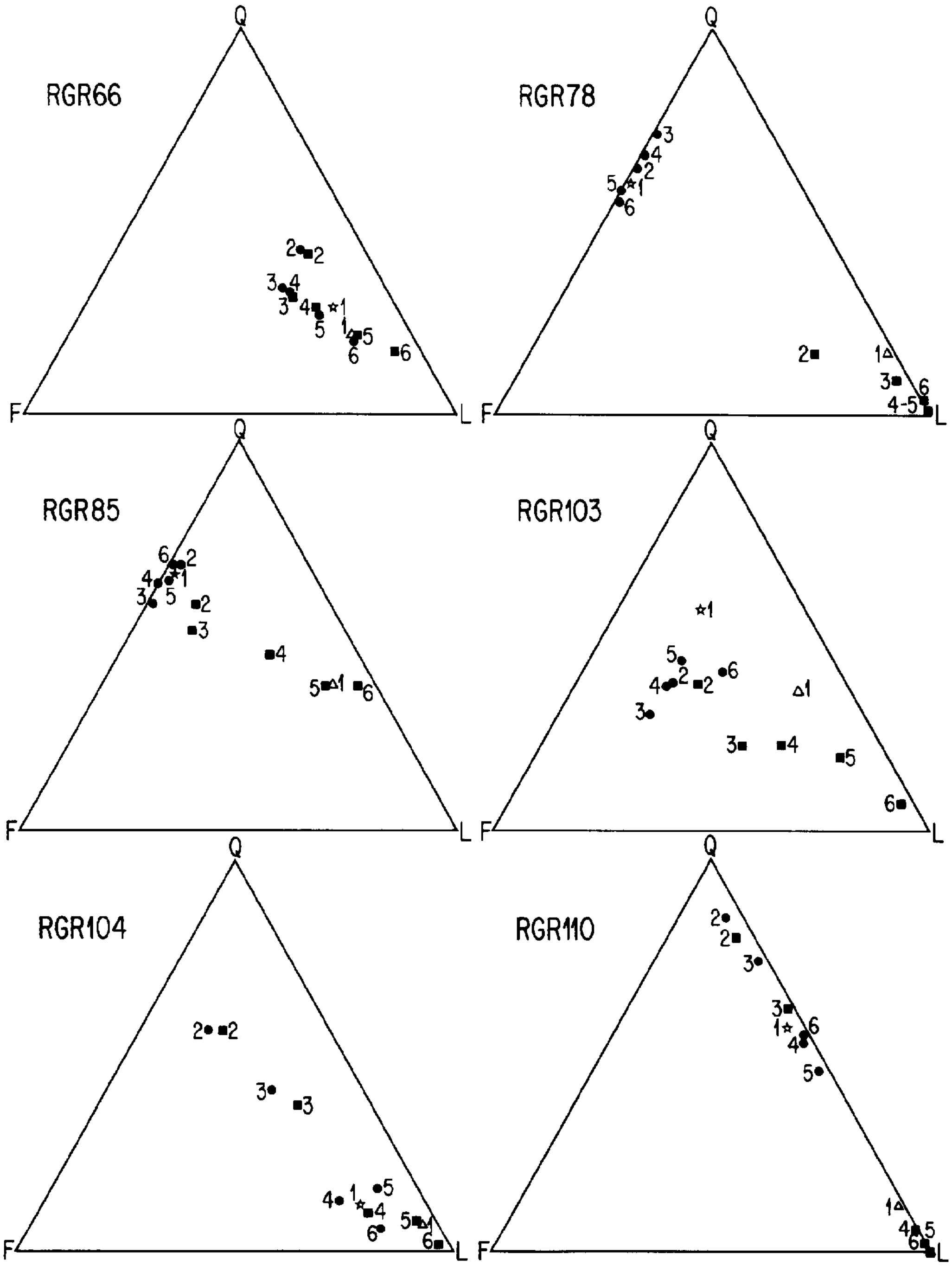

FIG. 1.—QFL triangles (see Table 1) for all 6 samples using both counting methods. Circles represent samples 2–6 (4–3 ϕ, 3–2 ϕ, 2–1 ϕ, 1–0 ϕ and 0–(−1) ϕ, respectively) using the Gazzi-Dickinson method; star represents Sample 1 (unsorted) using the Gazzi-Dickinson method. Squares represent Samples 2–6 using the traditional method; triangle represents Sample 1 using the traditional method. Same symbols are used in Figures 2–6. Samples RGR66 and RGR104 exhibit significant compositional variation with grain size no matter which counting method is used,

TABLE 2.—*Point-count data for unsieved fractions*

Sample	RGR66-1		RGR78-1		RGR85-1		RGR103-1		RGR104-1		RGR110-1	
Provenance	Felsic volcanics		Coarse schist		Mixed metamorphic		Mixed		Basalt and Sediments		Sediments	
Counting method	Gazzi-Dickinson	Traditional	Gazzi-Dickinson	Traditional	Gazzi-Dickinson	Traditional	Gazzi-Dickinson	Traditional	Gazzi-Dickinson	Traditional	Gazzi-Dickinson	Traditional
Qp	6	2	0	0	5	76	5	75	0	0	8	2
Qm	74	58	153	42	188	33	154	31	35	22	159	34
P	33	25	73	6	59	15	39	22	36	6	12	2
K	11	17	27	0	40	15	30	12	8	3	0	0
Lv	135	149	0	0	0	0	25	22	71	105	0	0
Lm	1	3	2	4	5	8	9	34	2	4	1	1
Ls	32	44	0	0	0	0	19	20	140	149	114	260
Lp	—	0	—	228	—	150	—	76	—	9	—	0
M	1	0	39	20	1	2	3	2	0	0	2	1
D	7	2	1	0	1	1	14	4	7	1	4	0
Misc.	0	0	5	0	1	0	2	2	1	1	0	0
Total	300	300	300	300	300	300	300	300	300	300	300	300

of the quartz grain in half, the composition would remain 91% Qm and 9% Lm. Thus, in the example given, use of the Indiana method results in the apparent formation of Lm from the breakage of Qm. This result would be difficult to explain from natural causes! Rather, it results from the counting method itself. In the above case, the Gazzi-Dickinson method produces more uniform, understandable results.

The above discussion illustrates that our "traditional" method is not identical to the Indiana method because we employed a zero-percent cutoff in all our counts. Nonetheless, results using our "traditional" method are likely to be far more similar to results acquired using the Indiana method than to those acquired using the Gazzi-Dickinson method.

RESULTS

Point-count data for the unsieved fractions of each of the six samples are shown in Table 2. This table illustrates the type of data collected and calculated for each size fraction of each sample. Data for both counting methods are given for each sample. The calculated QFL, LmLvLs, and QpLvmLsm percentages for all size fractions of each sample are listed in Table 3. Again, the data obtained using both counting methods are given for each sample.

Figure 1 shows QFL plots for each size fraction of each of the six samples using both methods. (The Indiana "school" uses the QFR notation. For clarity, it is recommended that future work using traditional methods be reported in the QFR notation, and that the QFL notation be used with the Gazzi-Dickinson method.) For Samples (RGR) 78, 85, 103 and 110, the points for each size fraction using the Gazzi-Dickinson method are more clustered than those using the traditional method. Samples 66 and 104 show scattering of points with both methods.

Figure 2 shows QpLvmLsm plots (Graham et al. 1976; Ingersoll and Suczek 1979) for Samples 66, 103, 104, and 110. Samples 78 and 85 are not shown because each has so few lithic fragments that this plot is statistically insignificant (Table 2). The triangular plots of Figure 2 show less variation with grain size than shown in Figure 1. Also, the points tend to cluster on these triangles using either counting method.

Figure 3 shows the variation in QFL% Q, F, and L versus grain size for Samples 85 and 104. For Sample 85, the Gazzi-Dickinson

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whereas the other four samples show significantly less compositional variation with grain size using the Gazzi-Dickinson method than using the traditional method. Notice tendency for unsorted samples (1) to have values near the averages of the other five samples, but generally closer to the coarser samples (4, 5, and 6) for either counting method (with the exception of Sample RGR103).

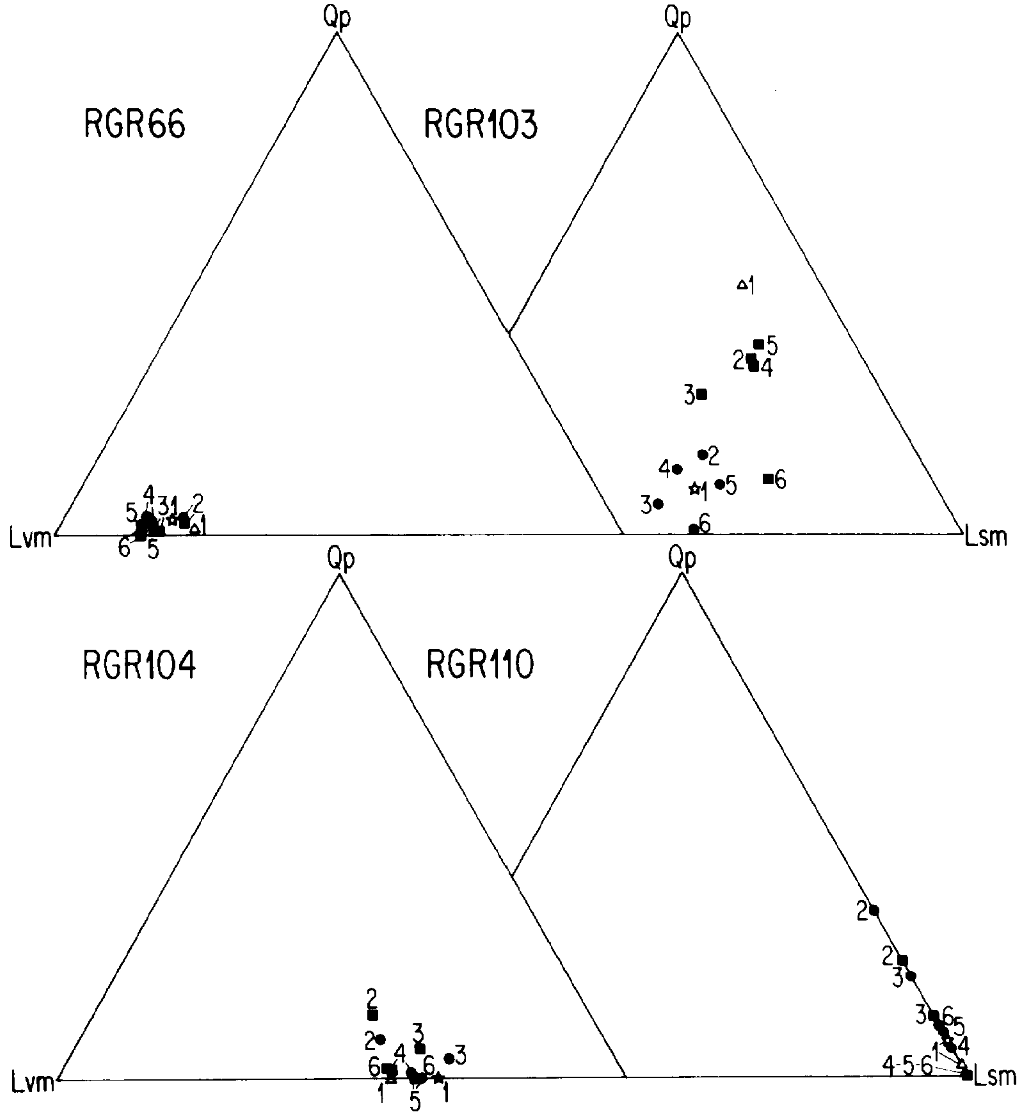

FIG. 2.—QpLvmLsm triangles (see Table 1) for four samples using both counting methods (Samples RGR78 and RGR85 have too few lithic fragments to be statistically significant). See Figure 1 for explanation of symbols. There is little compositional variation with grain size using either counting method, although Sample RGR103 shows considerable variation using the traditional method. The generally small amount of compositional variation indicates that this plot is a reliable indicator of provenance.

method shows much less variation due to grain size than the traditional method. Sample 104 shows considerable variation with grain size for both counting methods, although somewhat less using the Gazzi-Dickinson method, unless Fractions 2 and 3 (fine-grained) are not considered.

Figure 4 contains plots of LmLvLs and QpLvmLsm percentages versus grain size for two samples. Sample 103 shows considerable variation in LmLvLs percentages using either method; however, the Gazzi-Dickinson method systematically shows less variation with grain size. Both methods result in little

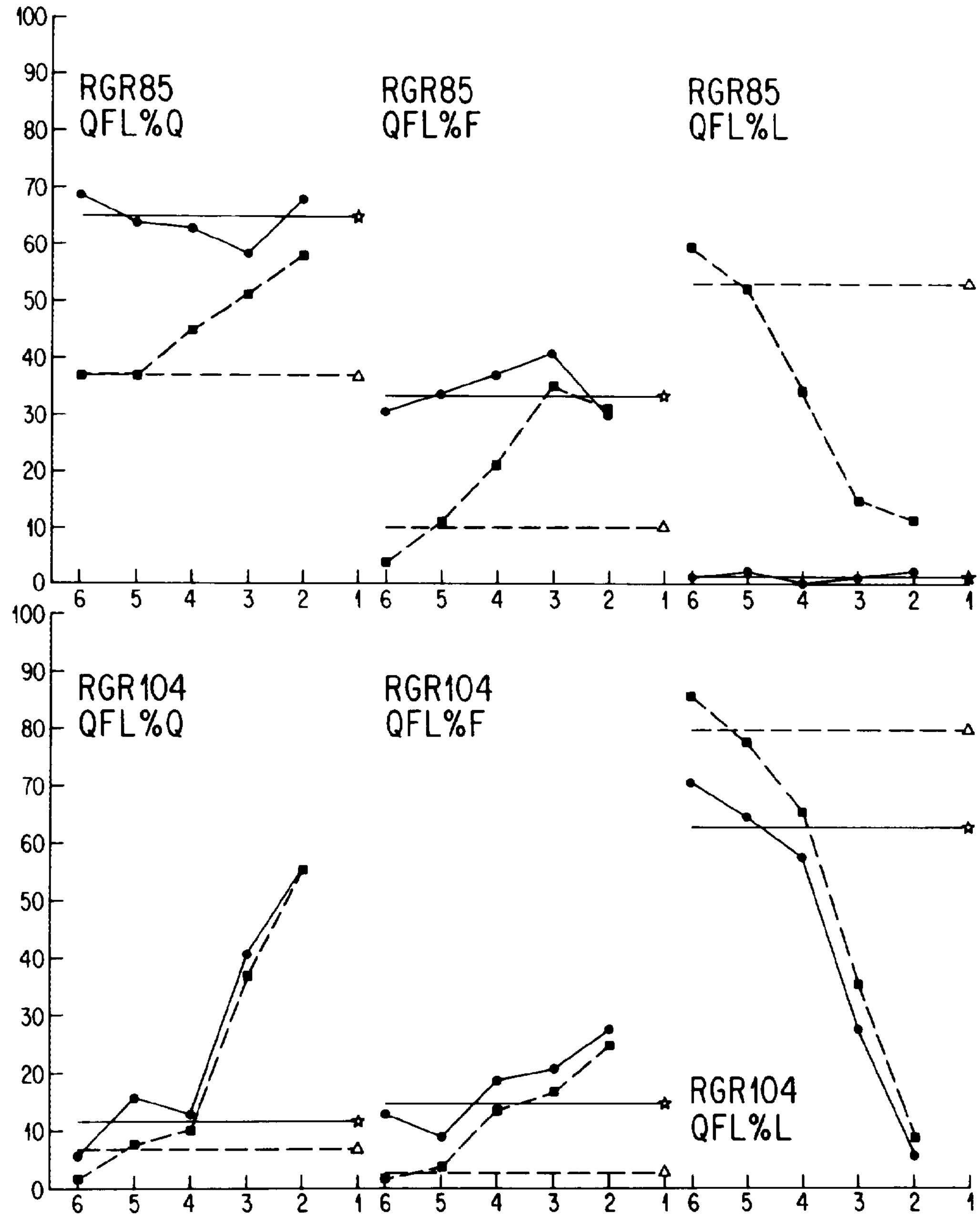

FIG. 3.—Binary plots of QFL% Q, F, and L versus grain size (coarser on left, finer on right, with Sample 1 being unsorted) for Samples RGR85 and RGR104. See Figure 1 for explanation of symbols. Solid lines connect results using Gazzi-Dickinson method; dashed lines connect results using the traditional method. Horizontal lines to left of unsorted samples (1) illustrate the degree to which these samples represent mean values. Total amount of compositional variation with grain size is less and the degree to which the unsorted sample represents the mean is greater using the Gazzi-Dickinson method than using the traditional method. Total amount of compositional variation is reduced considerably if the two finest fractions (2 and 3) are ignored.

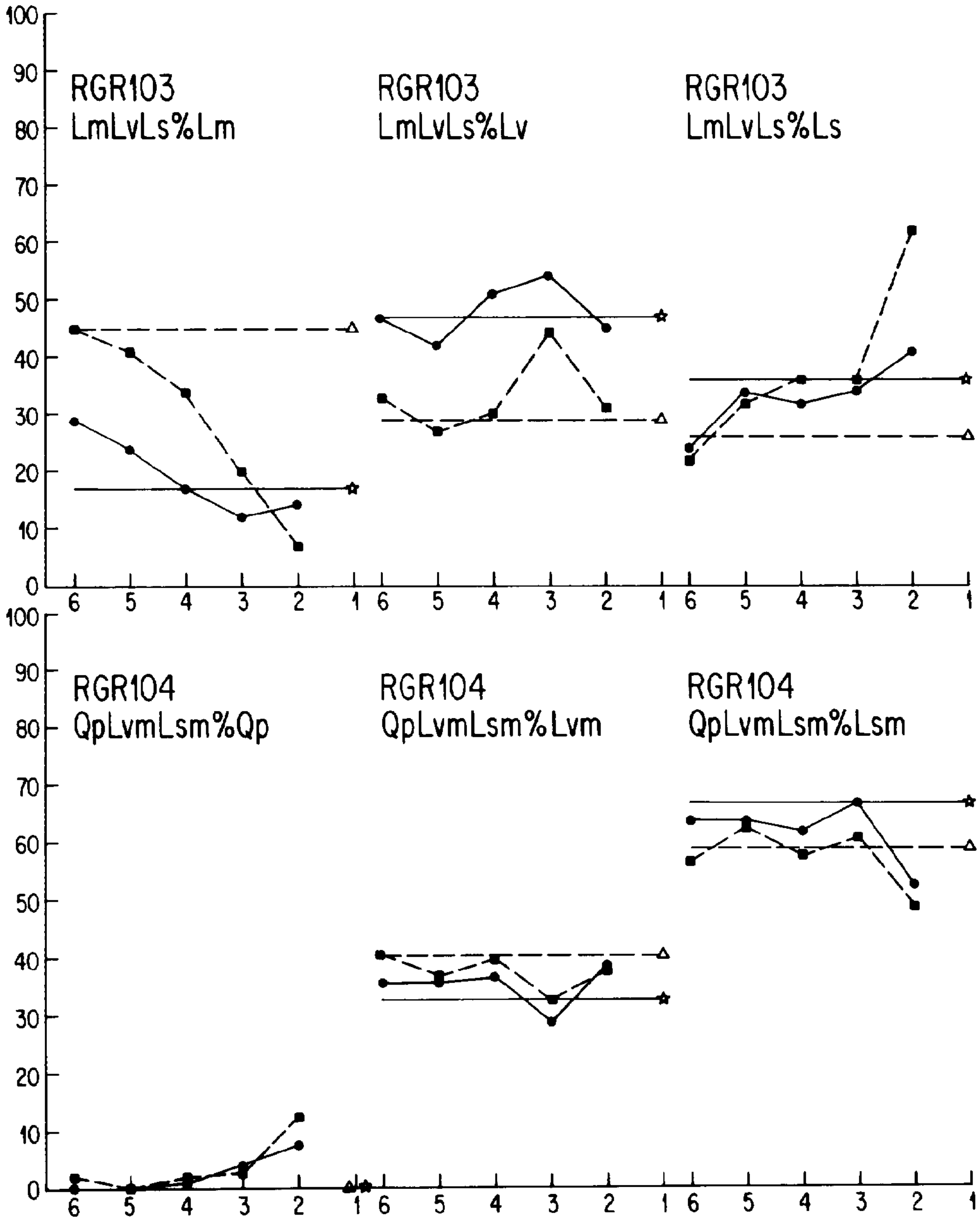

FIG. 4.—Binary plots of LmLvLs% Lm, Lv, and Ls (RGR103) and QpLvmLsm% Qp, Lvm, and Lsm (RGR104) versus grain size. See Figures 1 and 3 for explanation of symbols. Sample RGR103 shows significantly less compositional variation with grain size using the Gazzi-Dickinson method, whereas Sample RGR104 shows approximately the same degree of compositional variation with grain size regardless of counting method, but total amount of variation is small.

variation with grain size for QpLvmLsm percentages, as illustrated by Sample 104.

Examples of variations in parameter ratios with grain size, such as Qp/Q, Lv/L, and P/F, are shown in Figure 5. Again, the Gazzi-Dickinson method generally results in less variation than does the traditional method.

Figure 6 shows the variation in framework-

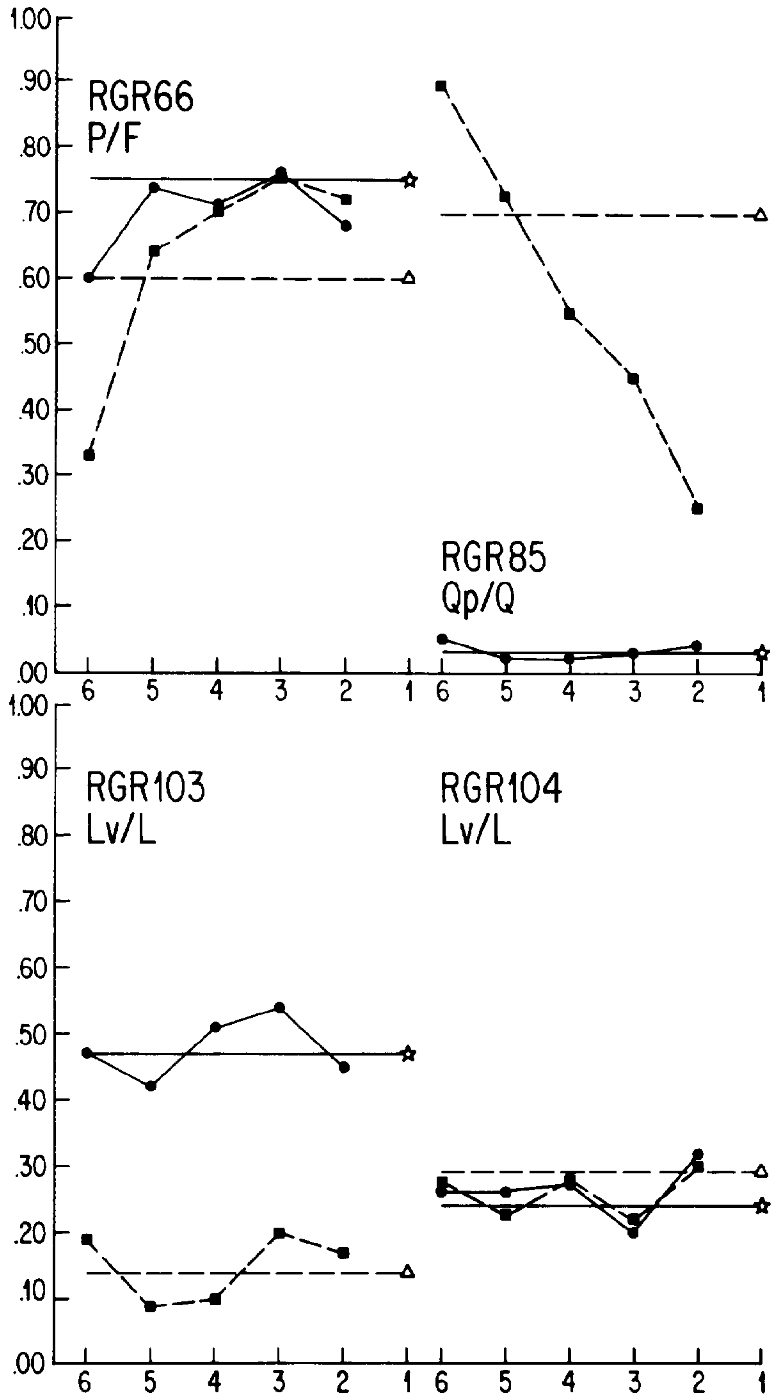

FIG. 5.—Binary plots of parameter ratios versus grain size. See Figures 1 and 3 for explanation of symbols. In most cases, the amount of compositional variation with grain size is either similar or less using the Gazzi-Dickinson method as compared to the traditional method.

TABLE 3.—*Recalculated Ternary percentages*

Sample (counting method)	QFL% Q	QFL% F	QFL% L	LmLv-Ls% Lm	LmLv-Ls% Lv	LmLv-Ls% Ls	QpLvm-Lsm% Qp	QpLvm-Lsm% Lvm	QpLvm-Lsm% Lsm
RGR66-1 (G-D)	27	15	58	1	80	19	3	78	19
RGR66-2 (G-D)	42	15	43	1	79	20	3	76	21
RGR66-3 (G-D)	32	24	44	1	84	15	2	82	16
RGR66-4 (G-D)	31	23	46	1	85	14	4	82	14
RGR66-5 (G-D)	25	19	56	0	86	14	2	84	14
RGR66-6 (G-D)	19	14	67	1	85	14	1	84	15
RGR66-1 (traditional)	20	14	66	2	76	22	1	75	24
RGR66-2 (traditional)	41	14	45	1	78	21	3	76	21
RGR66-3 (traditional)	30	23	47	1	82	17	1	81	18
RGR66-4 (traditional)	27	19	54	1	84	15	2	82	16
RGR66-5 (traditional)	20	13	67	0	83	17	1	82	17
RGR66-6 (traditional)	16	6	78	1	85	14	0	85	15
RGR78-1 (G-D)	60	39	1	100	0	0	0	0	100
RGR78-2 (G-D)	64	35	1	67	33	0	0	33	67
RGR78-3 (G-D)	73	26	1	50	0	50	0	0	100
RGR78-4 (G-D)	67	32	1	100	0	0	0	0	100
RGR78-5 (G-D)	58	42	0	—	—	—	—	—	—
RGR78-6 (G-D)	55	44	1	0	100	0	0	100	0
RGR78-1 (traditional)	15	2	83	100	0	0	0	0	100
RGR78-2 (traditional)	15	19	66	100	0	0	0	0	100
RGR78-3 (traditional)	8	4	88	67	0	33	0	0	100
RGR78-4 (traditional)	1	0	99	100	0	0	0	0	100
RGR78-5 (traditional)	1	0	99	100	0	0	0	0	100
RGR78-6 (traditional)	3	0	97	100	0	0	0	0	100
RGR85-1 (G-D)	65	33	2	100	0	0	50	0	50
RGR85-2 (G-D)	68	30	2	100	0	0	62	0	38
RGR85-3 (G-D)	58	41	1	100	0	0	71	0	29
RGR85-4 (G-D)	63	37	0	100	0	0	75	0	25
RGR85-5 (G-D)	64	34	2	100	0	0	36	0	64
RGR85-6 (G-D)	68	31	1	100	0	0	71	0	29
RGR85-1 (traditional)	37	10	53	100	0	0	91	0	9
RGR85-2 (traditional)	58	31	11	100	0	0	86	0	14
RGR85-3 (traditional)	51	35	14	100	0	0	96	0	4
RGR85-4 (traditional)	45	21	34	100	0	0	93	0	7
RGR85-5 (traditional)	37	11	52	100	0	0	84	0	16
RGR85-6 (traditional)	37	4	59	100	0	0	77	0	23
RGR103-1 (G-D)	57	24	19	17	47	36	9	43	48
RGR103-2 (G-D)	38	40	22	14	45	41	16	38	46
RGR103-3 (G-D)	30	49	21	12	54	34	6	51	43
RGR103-4 (G-D)	37	42	21	17	51	32	13	44	43
RGR103-5 (G-D)	44	35	21	24	42	34	10	38	52
RGR103-6 (G-D)	41	27	32	29	47	24	1	47	52
RGR103-1 (traditional)	36	12	52	45	29	26	50	14	36
RGR103-2 (traditional)	38	34	28	7	31	62	35	20	45
RGR103-3 (traditional)	22	32	46	20	44	36	28	32	40
RGR103-4 (traditional)	22	23	55	34	30	36	34	20	46
RGR103-5 (traditional)	19	11	70	41	27	32	38	17	45
RGR103-6 (traditional	7	3	90	45	33	22	11	29	60
RGR104-1 (G-D)	12	15	73	1	33	66	0	33	67
RGR104-2 (G-D)	56	28	16	2	42	56	8	39	53
RGR104-3 (G-D)	41	21	38	0	30	70	4	29	67
RGR104-4 (G-D)	13	19	68	0	37	63	1	37	62
RGR104-5 (G-D)	16	9	75	0	36	64	0	36	64
RGR104-6 (G-D)	6	13	81	0	36	64	0	36	64
RGR104-1 (traditional)	7	3	90	1	41	58	0	41	59
RGR104-2 (traditional)	56	25	19	4	44	52	13	38	49
RGR104-3 (traditional)	37	17	46	1	35	64	6	33	61
RGR104-4 (traditional)	10	14	76	0	41	59	2	40	58
RGR104-5 (traditional)	8	4	88	0	37	63	0	37	63
RGR104-6 (traditional)	2	2	96	0	42	58	2	41	57

TABLE 3.—*Continued*

Sample (counting method)	QFL% Q	QFL% F	QFL% L	LmLv-Ls% Lm	LmLv-Ls% Lv	LmLv-Ls% Ls	QpLvm-Lsm% Qp	QpLvm-Lsm% Lvm	QpLvm-Lsm% Lsm
RGR110-1 (G-D)	57	4	39	1	0	99	7	0	93
RGR110-2 (G-D)	85	4	11	0	0	100	33	0	67
RGR110-3 (G-D)	74	2	24	0	0	100	20	0	80
RGR110-4 (G-D)	53	2	45	0	0	100	6	0	94
RGR110-5 (G-D)	46	2	52	0	0	100	9	0	91
RGR110-6 (G-D)	55	1	44	0	0	100	10	0	90
RGR110-1 (traditional)	12	1	87	0	0	100	1	0	99
RGR110-2 (traditional)	80	4	16	0	0	100	23	0	77
RGR110-3 (traditional)	62	1	37	0	0	100	12	0	88
RGR110-4 (traditional)	6	0	94	0	0	100	0	0	100
RGR110-5 (traditional)	2	0	98	0	0	100	0	0	100
RGR110-6 (traditional)	0	0	100	0	0	100	0	0	100

percent phyllosilicates and framework-percent dense minerals with grain size. The two counting methods result in significant differences in these two percentages for some samples.

DISCUSSION

Point-counting methods are employed primarily to determine statistical representations of the modal compositions of rock samples. Variation of modal composition with changing grain size is due to 1) the breakage of grains during erosion, transport, and in situ weathering, and 2) actual mineralogic change with grain size. The latter may be caused by multiple lithologic sources contributing compositionally and texturally distinct grain sizes, and/or hydraulic or aerodynamic sorting of grains of variable density and/or shape.

Results using the Gazzi-Dickinson method are not affected significantly by the breakage of grains, but are affected by the segregation of minerals (see, for example, Fig. 1; Sample 104). Results using the traditional method are affected by both factors, as indicated by the large variation of composition with different grain size (Fig. 1) for all samples. Using the traditional method, there are fewer lithic fragments as grain size decreases (Fig. 1). The Gazzi-Dickinson method is based almost solely on composition (except for the size range between .03 and .0625 mm); thus, results are not influenced by grain size due to the breakage of grains, but are influenced by fundamental compositional differences in grain sizes, as with any point-counting method.

Use of either counting method results in greater similarity of modal composition be-

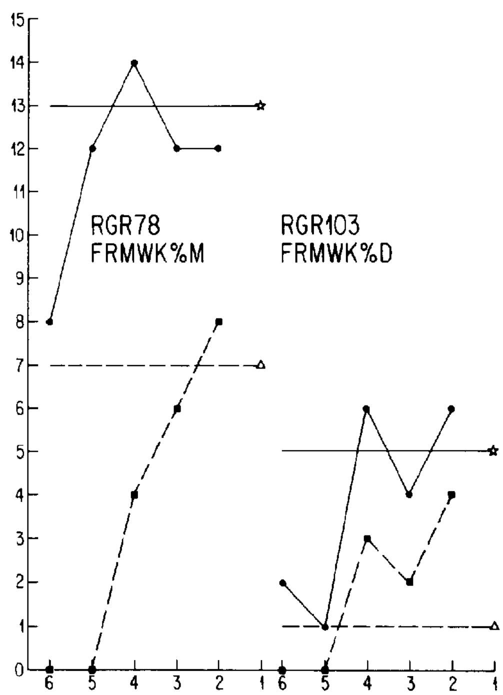

FIG. 6.—Binary plots of framework% phyllosilicates (M) and dense minerals (D) versus grain size. See Figures 1 and 3 for explanation of symbols. Compositional variation with grain size is fairly high using either method, although Gazzi-Dickinson method produces more uniform results for Sample RGR78. The other four samples (RGR66, RGR85, RGR104, and RGR110) produced similar results using both counting methods.

tween coarse-grained and unsorted samples, and less similarity between fine-grained and unsorted samples. This result probably is due to the lesser volume of fine components relative to coarse components of each unsorted sample.

The QFL percentages for each sample are consistently more variable than are the QpLvmLsm and LmLvLs percentages using the traditional method (Figs. 1–4). These results suggest that lithic proportions are better indicators of source rocks than are QFL percentages no matter what method is used. In addition, the Gazzi-Dickinson method provides more consistent results for all parameters. A scarcity of lithic fragments within an unsorted sample using the Gazzi-Dickinson method implies coarse-grained source rocks, whereas using the traditional method, lithic fragments generally are scarce only in fine-grained fractions. Therefore, their absence in an unsorted sample may not have source-rock significance using the traditional method. Recognition of the type of coarse-grained source rocks using either method must rely on a combination of parameters such as QFL, P/F, M, and D, and other techniques such as degree of polycrystallinity of quartz (Basu et al. 1975).

IMPLICATIONS AND CONCLUSIONS

The results of this study show that the Gazzi-Dickinson method of point-counting sand/sandstone has distinct advantages over traditional methods of determining modal compositions for the purpose of differentiating source rocks. The three primary advantages are 1) more uniform results are obtained for any grain size, including unsorted samples; 2) sieving and multiple counts of different fractions are unnecessary; and 3) counts are completed more quickly and with less ambiguity, especially for poorly sorted, diagenetically altered sandstones ("graywackes"). These results are especially significant for the construction and use of actualistic petrologic models because identical petrographic methods can be applied to modern sands and ancient sandstones. Traditional methods that rely on sieving cannot be applied to poorly sorted sandstones because of the variability of grain size and, hence, the variability of composition. In addition, identification of original grain sizes in highly compacted sandstones is extremely difficult, thus rendering impractical the counting of a single grain size within a poorly sorted, compacted sandstone. Use of the Gazzi-Dickinson method provides confidence that similar source rocks will produce similar modal compositions no matter what the grain size or the compactional history of the sediment. Naturally, these generalizations only apply to situations in which other factors such as transportation, depositional environment, and diagenesis are subordinate in importance. Situations where this commonly is the case include areas of active tectonism/magmatism, and rapid accumulation and burial of detritus. Using these methods, actualistic petrologic models relating sand/sandstone composition directly to tectonic setting (for example, Dickinson and Suczek 1979; Ingersoll and Suczek 1979) gain futher credibility. Therefore, we recommend universal use of the Gazzi-Dickinson point-counting method for determining source rocks based on modal composition of sand and sandstone.

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