DETRITAL MODES OF SELECTED SANDSTONE SAMPLES FROM THE McCOY MOUNTAINS FORMATION AND CORRELATIVE UNITS IN SOUTHWESTERN ARIZONA

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Detrital Modes of Selected Sandstone Samples from the McCoy Mountains Formation and Correlative Units in Southwestern Arizona

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Previous workers have established the general petrologic character of the McCoy Mountains Formation and equivalent Jurassic-Cretaceous units in southwestern Arizona and southeastern California by point-counting the detrital modes of 170 sandstones and metasandstones (Robison, 1979; Harding, 1980, 1982; Harding and Coney, 1985; Laubach et al., 1987; Richard et al., 1987; Fackler-Adams et al., 1997). Many of the samples studied, however, are foliated to varying degrees, with neomorphic growth of metamorphic minerals partly obscuring detrital textures and compositions. For this report, a set of control samples was collected from the least deformed and least altered rocks that could be found exposed in mountain ranges of southwestern Arizona.

Guidance to favorable outcrops was provided by S.M. Richard, D.R. Sherrod, and J.E. Spencer, and Jacqueline Dickinson provided field assistance. Sampling was confined to traverses through well mapped stratigraphic successions. Of 80 thin sections prepared from the collection, 30 were selected as suitable for the point counting of original detrital modes without ambiguity. Five samples were chosen from each of six local stratigraphic sequences sampled. Table 1 lists the categories of grain types and other constituents for which percentages are reported. Volcanic and sedimentary lithic fragments were not tabulated separately from metavolcanic and metasedimentary lithic fragments, respectively, because of the difficulty of distinguishing between alteration in the source terranes for the sediment and intrastratal alteration after deposition. Sections were stained to discriminate between plagioclase and K-feldspar. Most samples were collected in 1983 and 1985 with field support from NSF Grant EAR-8417106, which also provided funds for thin sections.

Crystal Hills Succession

Strata sampled from the Crystal Hills of the southern Quartzsite Quadrangle (Fig. 1) were mapped as "continental red-bed deposits" of Mesozoic (?) age by Miller (1970), are petrologically representative of "basal sandstone member 1" (of the McCoy Mountains Formation) of Harding and Coney (1985), and were mapped as "Crystal Hill formation" by Richard et al. (1993). In nearby outcrops, strata contiguous with the sampled Crystal Hills succession concordantly overlie Jurassic volcanic rocks that regionally underlie the McCoy Mountains Formation, and are overlain unconformably by strata forming the base of the upper McCoy Mountains Formation (Tosdal and Stone, 1994). Sand frameworks are dominantly well sorted quartz grains (Table 2), reflective of derivation from a cratonal provenance and presumably delivered to the McCoy basin from the continental surface to the northeast. Grain boundaries are interpenetrative, either sutured or concavo-convex, but the morphology of intracrystalline dust trains delineating locally preserved contacts between grain cores and quartz overgrowths show that the detrital sand grains were originally rounded to subrounded. Lithic fragments are predominantly sedimentary or metasedimentary, with volcanic rock fragments absent or rare. Proportions of pelitic, chert-metachert, and microgranular grains (Table 1) vary, but pelitic grains are typically most abundant, with microgranular grains typically least abundant. The absence of any feldspar grains in more than trace amounts precludes contributions from either volcanic or uplifted basement sources.

Ranegras Succession

Strata sampled from a low spur of the western Little Harquahala Mountains east of Pyramid Peak in the Hope Quadrangle (Fig. 2) were mapped as Ranegras Member of the McCoy Mountains Formation by Spencer et al. (1985). In one exposure, the Ranegras Member apparently underlies the Harquar Member (next section) concordantly, but the contact is faulted in most places. Samples from the Ranegras Member are less quartzose than typical representatives of "basal sandstone member 1" and less lithic than "basal sandstone member 2" of the McCoy Mountains Formation (Harding, 1982; Harding and Coney, 1985), but apparently represent a subquartzose petrofacies present also within the lower McCoy Mountains Formation. Abundant chert-metachert grains (Table 3) bring the content of total quartzose grains (QFL%) to the level of 74%-79%. The dominance of sedimentary-metasedimentary rock fragments over volcanic rock fragments, with pelitic and microgranular grains subequal in overall abundance, show a closer petrologic affinity of the Ranegras Member to "basal sandstone member 1" than to "basal sandstone member 2" of Harding and Coney (1985). However, the presence of significant feldspar (QFL% = 9-16) suggests sources partly in uplifted basement, perhaps exposed along a highstanding rift shoulder of the McCoy basin analogous to the Mogollon paleohighland flanking the coeval Bisbee basin farther east in Arizona. The dominance of K-feldspar over plagioclase is compatible with that interpretation, but precludes derivation of the Ranegras sands from simple mixing of quartzose and volcaniclastic lower McCoy grain aggregates. A more proximal source for sandstones of the Ranegras succession, in comparison to sandstones of the Crystal Hills succession, is favored by the generally coarser grain size, somewhat lesser sorting, and subangular to subrounded character of the grain aggregates within the former.

Harquar Succession

Strata sampled from a spur rising to Harquar Peak in the Little Harquahala Mountains of the Hope Quadrangle (Fig. 2) were mapped as Harquar Member of the McCoy Mountains Formation by Spencer et al. (1985). In nearby outcrops, strata contiguous with the sampled Harquar succession rest gradationally on the Hovatter Volcanics, which have yielded a U-Pb age (isochron intercept) of 166±11 Ma (Asmerom et al., 1991), comparable to the age of Jurassic volcanic rocks that regionally underlie the McCoy Mountains Formation (Reynolds et al., 1987; Richard et al., 1987; Fackler-Adams et al., 1997). The modal compositions (Table 4) of the largely volcaniclastic sandstones from the Harquar succession are closely comparable to "basal sandstone member 2" of the

McCoy Mountains Formation (Harding, 1982; Harding and Coney, 1985). The feldspar grains (QFL%F = 28-33) are predominantly plagioclase, and the volcanic rock fragments are predominantly felsite similar to volcanic rocks that underlie the McCoy Mountains Formation. Commonly straight extinction, locally resorbed margins, and rare inclusions of felsitic groundmass material suggest that much of the variable but subordinate quartz (QFL%Qm = 7-24) was derived from phenocrysts in felsic volcanic rocks. Volcanic rock fragments contain some microphenocrysts of plagioclase or quartz, or both, although the latter are not nearly as abundant as the former. The presence of some quartz grains with undulatory extinction and of minor perthitic K-feldspar implies, however, that the volcanic debris was admixed with detritus derived from basement sources analogous to those that contributed detritus to the Ranegras Member (previous section). The complementary proportions of quartz grains and volcanic lithic fragments probably reflects the degree of mixing for each sample, and the percentage of sedimentary-metasedimentary lithic fragments increases in parallel with increases in the percentage of quartz grains (Table 4). The subrounded to subangular character of the grain aggregates is compatible with proximal sources, and more easily abraded rock fragments are distinctly better rounded than associated mineral grains. Despite uncertainty, from field mapping, concerning the stratigraphic placement of the Harquar Member, its sedimentary petrology demonstrates clearcut affinity with the lower McCoy Mountains Formation, and none with the upper McCoy Mountains Formation.

Ramsey Mine Succession

Strata sampled south of Ramsey Mine (Fig. 3) near the western edge of the Vicksburg Quadrangle were mapped as "sedimentary rocks of Ramsey Mine" by Sherrod and Koch (1987), and as the "sedimentary rocks member" of the "sedimentary and volcanic rocks of Ramsey Mine" by Sherrod et al. (1990), with the implication that the section correlates with some part of the McCoy Mountains Formation (Sherrod and Koch, 1987). The local sequence overlies quartz porphyry similar lithologically to volcanic rocks that underlie the McCoy Mountains Formation elsewhere. Sandstones of the Ramsey Mine succession are more variable in their content of volcanic rock fragments than sandstones of the Harquar succession, but are otherwise comparable petrologically (Table 5), with abundant volcanic rock fragments of generally felsitic character consistently dominant over sedimentary-metasedimentary rock fragments, and plagioclase dominant over K-feldspar. As for the Harquar succession, the percentages of sedimentary-metasedimentary lithic fragments and quartz grains generally increase in parallel as the percentages of volcanic lithic fragments decrease (Table 5).

Livingston Hills Succession

Strata sampled from near the southern edge of the Quartzsite Quadrangle and the northern edge of the Livingston Hills Quadrangle were collected along a north-south traverse across the Livingston Hills (Fig. 1) through strata mapped as "Livingston Hills Formation" by Miller (1970), described under the same name by Harding (1980), and assigned to the Upper Cretaceous "upper unit" of the McCoy Mountains Formation by

Tosdal and Stone (1994). Sandstones of the Livingston Hills succession are more arkosic (Table 6) than either the quartzose or the lithic sandstones of the lower McCoy Mountains Formation, and closely resemble petrofacies within the various informally named members of the upper McCoy Mountains Formation as designated by Harding and Coney (1985). Quartz content is moderate (QFL% = 23-34), with total feldspar uniformly more abundant (QFL% = 37-54), and plagioclase is consistently more abundant than K-feldspar (P/K = 1.2 to 3.1). On average, sedimentary-metasedimentary rock fragments, dominantly pelitic, are three times as abundant as volcanic rock fragments. From the overall stratotectonic framework of the McCoy basin in Late Cretaceous time, derivation of the detritus from basement uplifted along the Maria fold-and-thrust belt to the north is inferred (Tosdal, 1990; Miller et al., 1992; Tosdal and Stone, 1994).

Apache Wash Succession

Strata sampled along an east-west traverse following a side canyon of upper Apache Wash (Fig. 3) in the southern Plomosa Mountains of the Quartzsite Quadrangle were mapped as "Livingston Hills Formation" by Miller (1970), but treated as a separate "Apache Wash Formation" of uncertain stratigraphic position by Harding (1982) and Harding and Coney (1985), and discussed later as part of the "Apache Wash sequence" by Richard et al. (1993). The sampled Apache Wash succession overlies a thick lens of megabreccia (Richard, 1992), which in turn overlies the "Crystal Hill formation" of the lower McCoy Mountains Formation (Richard et al., 1993), and can therefore be regarded as part of the upper McCoy Mountains Formation. Earlier uncertainty concerning the stratigraphic position of the Apache Wash sequence stemmed from misidentification of the megabreccia body as Paleozoic sedimentary and Jurassic volcanic bedrock (Miller, 1970; Harding, 1982; Harding and Coney, 1985). Although containing somewhat more quartz (QFL% = 40-52) than sandstones of the Livingston Hills succession, sandstones of the Apache Wash succession (Table 7) display detrital modes generally compatible with assignment to the upper McCoy Mountains Formation. Both feldspars (QFL%F = 14-24) are present in significant proportions (P/K = 1.8 to 2.2), and non-calcareous sedimentary-metasedimentary rock fragments are on average four to five times as abundant as volcanic rock fragments. A unique facet of the detrital modes among the sample suites studied for this report is the consistent presence of subordinate (QFL% = 3-10) limeclasts reworked from Paleozoic source rocks that were presumably exposed to erosion within the Maria fold-and-thrust belt. Addition of a significant proportion of reworked sedimentary detritus to basement detritus may well account for the higher quartz content and lower feldspar content of the Apache Wash succession as compared to the Livingston Hills succession.

Comparative Detrital Modes

Figures 4-7 are QtFL, QmFLt, QpLvmLsm, and QmPK triangular compositional diagrams (Dickinson, 1985) allowing summary comparisons to be made among the six sample suites described in this report. All four diagrams show that the Harquar and Ramsey Mine successions occupy closely adjacent to overlapping compositional fields, with mean compositions nearly the same, and show them to be the most lithic sandstones

(Figs. 4-5), with the highest proportion of volcanic rock fragments (Fig. 6) and the highest ratio of plagioclase to K-feldspar (Fig. 7), reflective of their dominantly volcaniclastic character. The less lithic and more arkosic (Figs. 4-5) Livingston Hills succession displays a comparable ratio of feldspar to quartz, but a distinctly higher ratio of K-feldspar to plagioclase (Fig. 7), reflecting contributions from plutonic sources in Mesozoic plutons or Precambrian basement, and only a slightly greater proportion of volcanic rock fragments than are displayed by the other non-volcaniclastic successions (Fig. 6). The Crystal Hills succession is clearly the most quartzose, and the Ranegras succession shifts the farthest in compositional space from the QtFL diagram to the QmFLt diagram because of its higher proportion of chert-metachert grains (Figs. 4-5), which place it apart from the other non-volcaniclastic successions on the QpLvmLsm diagram (Fig. 6). The Apache Wash succession is distinctly less feldspathic than the arkosic Livingston Hills succession (Figs. 4-5), but the P/K ratios of the two are similar (Fig. 7), as are the Qt/L and Qm/Lt ratios. Proportions of non-calcareous rock fragments are also nearly the same for the Apache Wash and Livingston Hills successions of the upper McCoy Mountains Formation (Fig. 6). On three of the diagrams (Figs. 4-5, 7), the Apache Wash succession plots in intermediate positions, on potential mixing lines, between the quartzose to subquartzose (Crystal Hills, Ranegras) and the volcaniclastic (Harquar, Ramsey Mine) suites of the lower McCoy Mountains Formation, and may contain intermingled detritus derived from various parts of the lower McCoy Mountains Formation deformed within the Maria fold-and-thrust belt during Late Cretaceous time. The lower ratio of K-feldspar to plagioclase in the Apache Wash succession, as compared to the Livingston Hills succession, may reflect a lower proportion of detritus derived directly from uplifted basement in the former (Fig. 7).

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Table 1. Framework grain types and other constituents of point-counted sandstones
[A & B reported as QFL%, where QFL = A+B; C reported as Frmwk% where Fmwrk (framework) = A+B+C; D reported as WR% where WR (whole rock) = A+B+C+D]

A. Monocrystalline Grains[1]	
Qm	quartz
P	plagioclase feldspar
K	K-feldspar
F (= P + K)	total feldspar
B. Polycrystalline Lithic Fragments[1]	
Qp	chert-metachert (& polycrystalline quartz from metaquartzite, vein quartz, etc.)
Lvm	volcanic-metavolcanic, include microlitic and felsitic grains
Lsm	sedimentary-metasedimentary (Lc = detrital limeclasts); include pelitic (argillite-shale-slate-phyllite) and microgranular (siltstone-hornfels) grains
L (= Lvm + Lsm)	total labile lithic fragments
Lt (=L + Qp)	total lithic fragments
[A-B]: Qt (= Qm + Qp)	total quartzose grains (monocrystalline and polycrystalline)
C. Accessory Mineral Grains	
pyx	pyroxene
opa	opaque iron oxide (dominantly magnetite)
D. Interstitial Materials	
mat[2]	detrital or diagenetic matrix (dominantly pyllosilicates)
cem	pore-filling cement (calcite)
int (= mat + cem)	total interstitial materials

[1] A & B distinguished by Gazzi-Dickinson convention (Ingersoll et al., 1984), whereby quartz-feldspar microphenocrysts and other intra-lithic quartz-feldspar crystals of sand size (or larger) are recalculated as quartz and feldspar grains (A) for detrital modes, insuring that lithic fragments (B) of detrital modes are exclusively aphanitic materials with internal polycrystalline constituents smaller than sand in size.

[2] Matrix distinguished from framework grains (A+B+C) on the basis of grain size, with matrix constituents uniformly smaller than sand in size (<0.0625 mm)

Table 2. Detrital modes of sandstones from Crystal Hills succession

	SW-Q-6	SW-Q-9	SW-Q-12	SW-Q-14	SW-Q-15	mean
Qm	92	90	86	82	83	87 ± 4
Qp	2	2	5	6	6	4 ± 2
Qt	94	92	91	88	89	91 ± 2
P	-	-	-	-	-	0
K	-	-	-	-	-	0
F	-	-	-	-	-	0
Lvm	-	-	-	1	0	tr
Lsm	6	8	9	11	11	9 ± 2
L	6	8	9	12	11	9 ± 2
Lt	8	10	14	18	17	13 ± 4
mat	5	6	8	8	9	7 ± 1
cem	-	4	-	8	-	-
int	5	10	8	16	9	-

Table 3. Detrital modes of sandstones from Ranegras succession

	SW-H-27	SW-H-31	SW-H-33	SW-H-34	SW-H-35	mean
Qm	57	59	65	64	63	62 ± 3
Qp	22	15	14	11	15	15 ± 4
Qt	79	74	79	75	78	77 ± 2
P	3	3	5	5	5	4 ± 1
K	12	9	10	9	11	10 ± 1
F	15	12	15	14	16	14 ± 1
Lvm	2	4	2	2	1	2 ± 1
Lsm	4	10	4	9	5	6 ± 3
L	6	14	6	11	6	9 ± 3
Lt	28	29	20	22	21	24 ± 4
mat	7	8	7	9	10	8 ± 1
cem	3	tr	5	-	5	3 ± 2
int	10	8	12	9	15	11 ± 2

Table 4. Detrital modes of sandstones from Harquar succession

	SW-H-15	SW-H-17	SW-H-20	SW-H-22	SW-H-24	mean
Qm	24	7	11	8	22	14 ± 7
Qp	5	-	1	4	2	2 ± 2
Qt	29	7	12	12	24	17 ± 8
P	26	31	27	29	26	28 ± 2
K	2	2	1	2	2	2 ± 0
F	28	33	28	31	28	30 ± 2
Lvm	33	56	52	50	37	46 ± 9
Lsm	10	4	8	7	11	8 ± 2
L	43	60	60	57	48	54 ± 7
Lt	48	60	61	61	50	56 ± 6
opa	4	1	4	2	4	3 ± 1
mat	3	14	10	11	12	-
cem	15	-	-	-	-	-
int	18	14	10	11	12	13 ± 3

Table 5. Detrital modes of sandstones from Ramsey Mine succession

	RM-1	RM-2	SMM-1	SW-V-3	SW-V-4	mean
Qm	9	13	19	8	18	13 ± 4
Qp	3	3	3	3	4	3 ± 0
Qt	12	16	22	11	22	17 ± 5
P	11	29	33	15	36	25 ± 10
K	1	3	8	2	5	4 ± 2
F	12	32	41	17	41	29 ± 12
Lvm	72	38	31	69	26	47 ± 19
Lsm	4	14	6	3	11	8 ± 4
L	76	52	37	72	37	55 ± 17
Lt	79	55	40	75	41	58 ± 16
pyx	4	-	-	1	-	-
mat	22	15	13	21	13	17 ± 4

Table 6. Detrital modes of sandstones from Livingston Hills succession

	SW-LH-23	SW-LH-24	SW-LH-26	SW-LH-27	SW-LH-28	mean
Qm	33	34	27	25	23	28 ± 4
Qp	2	2	7	8	10	6 ± 3
Qt	35	36	34	33	33	34 ± 1
P	33	30	28	23	23	27 ± 4
K	20	24	9	15	19	17 ± 5
F	53	54	37	38	42	45 ± 7
Lvm	3	2	11	11	8	7 ± 4
Lsm	9	8	18	18	17	14 ± 6
L	12	10	29	29	25	21 ± 8
Lt	14	12	36	37	35	18 ± 11
mat	9	11	13	11	10	11 ± 1
cem	-	-	-	1	-	-

Table 7. Detrital modes of sandstones from Apache Wash succession

	SW-Q-26	SW-Q-29	SW-Q-31	SW-Q-32	SW-Q-34	mean
Qm	45	52	44	40	49	46 ± 4
Qp	6	3	4	5	6	5 ± 1
Qt	51	55	48	45	55	51 ± 4
P	16	13	12	13	9	13 ± 2
K	8	7	6	6	5	6 ± 1
F	24	20	18	19	14	19 ± 3
Lvm	3	5	4	5	2	4 ± 1
Lsm	22	20	30	31	29	26 ± 4
(Lc)	(4)	(5)	(8)	(10)	(3)	(6 ± 3)
L	25	25	34	36	31	30 ± 5
Lt	31	28	38	41	37	35 ± 5
mat	10	14	12	13	14	13 ± 1

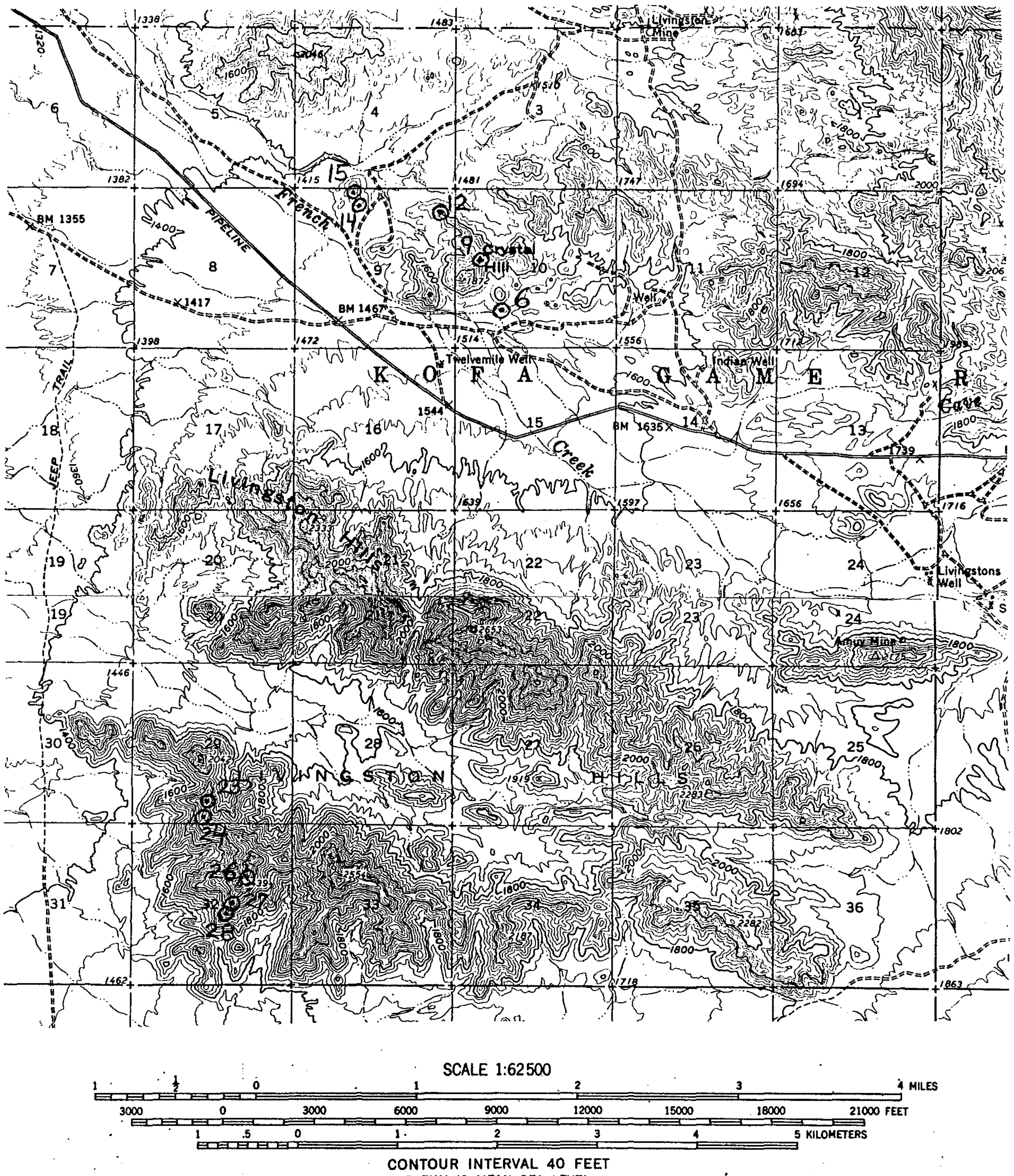


Figure 1. Adjoining segments of Quartzsite (above) and Livingston Hills (below) Quadrangles showing sample localities for Crystal Hills and Livingston Hills successions; sample number prefix SW-Q- for Crystal Hills samples 6,9,12,14,15 (Table 2) and SW-LH- for Livingston Hills samples 23, 24, 26, 27, 28 (Table 6).

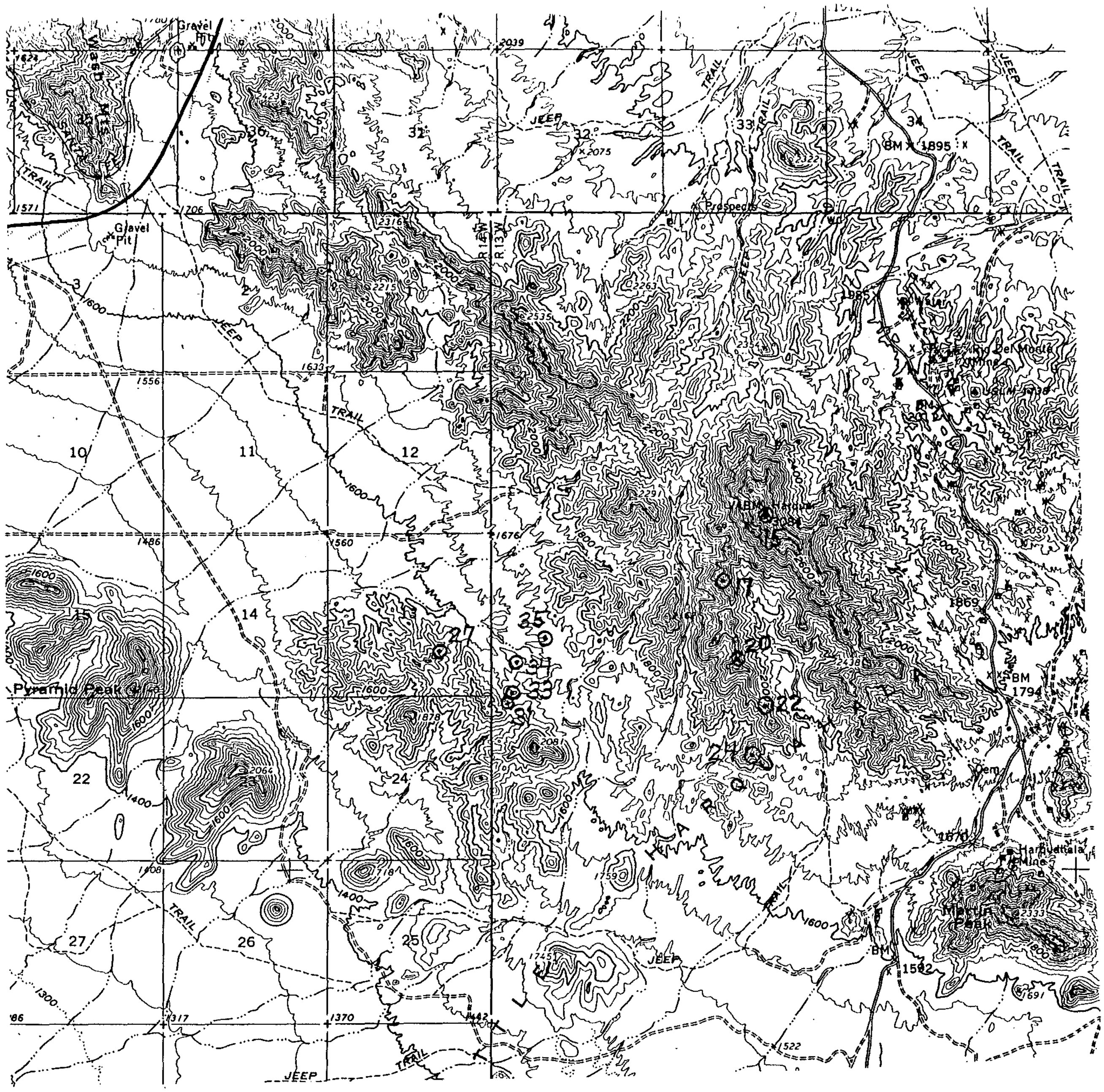


Figure 2. Segment of Hope Quadrangle showing sample localities for Ranegras and Harquar successions; sample number prefix SW-H- for Ranegras samples 27, 31, 33, 34, 35 (Table 3) and Harquar samples 15, 17, 20, 22, 24 (Table 4); see Figure 1 for scale.

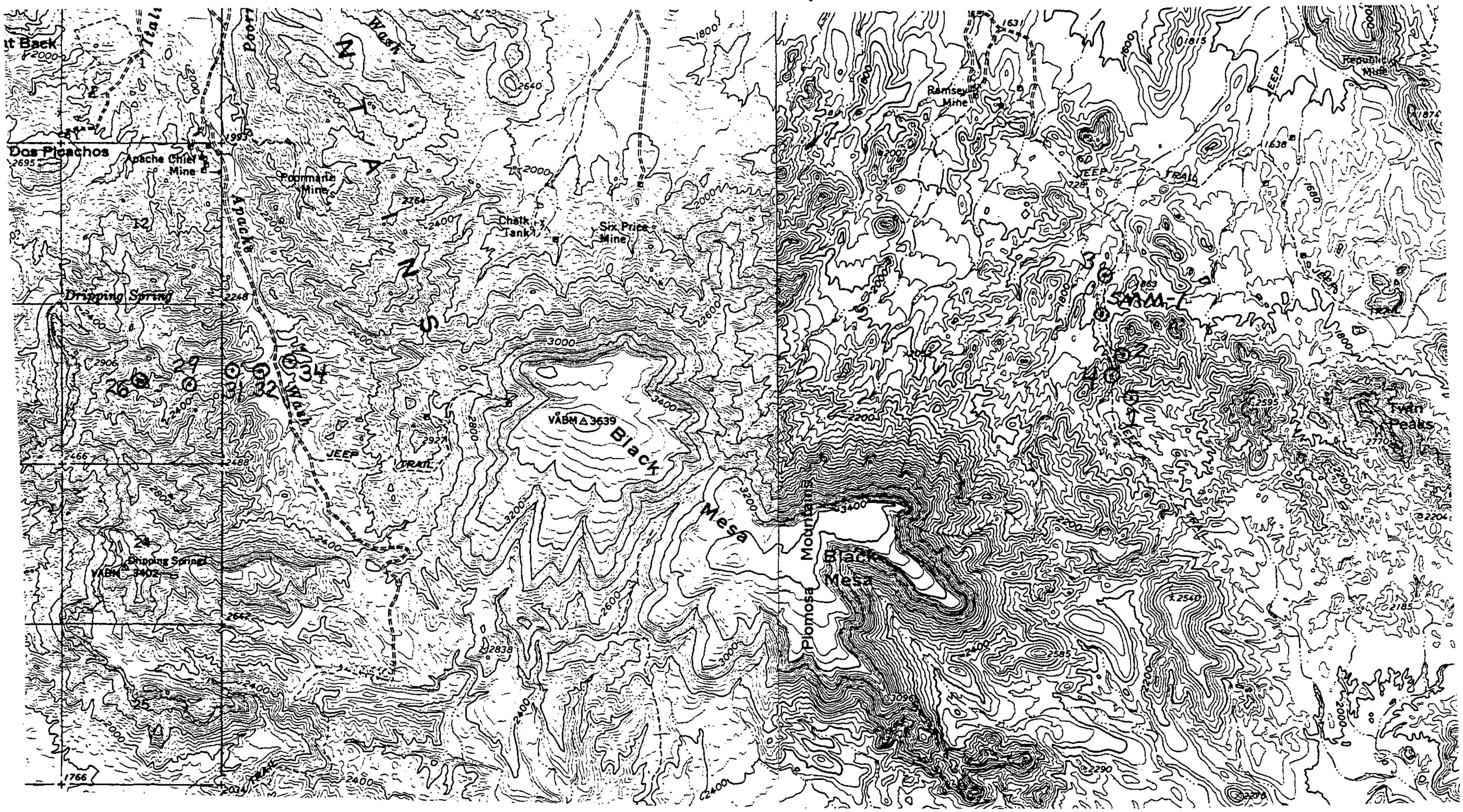


Figure 3. Adjoining segments of Quartzsite (left) and Vicksburg (right) Quadrangles showing sample localities for Ramsey Mine and Apache Wash successions; sample number prefix RM- for Ramsey Mine samples 1 & 2, SW-V- for Ramsey Mine samples 3 & 4 (Table 5), and SW-Q- for Apache Wash samples 26, 29, 31, 32, 34 (Table 7); see Figure 1 for scale.

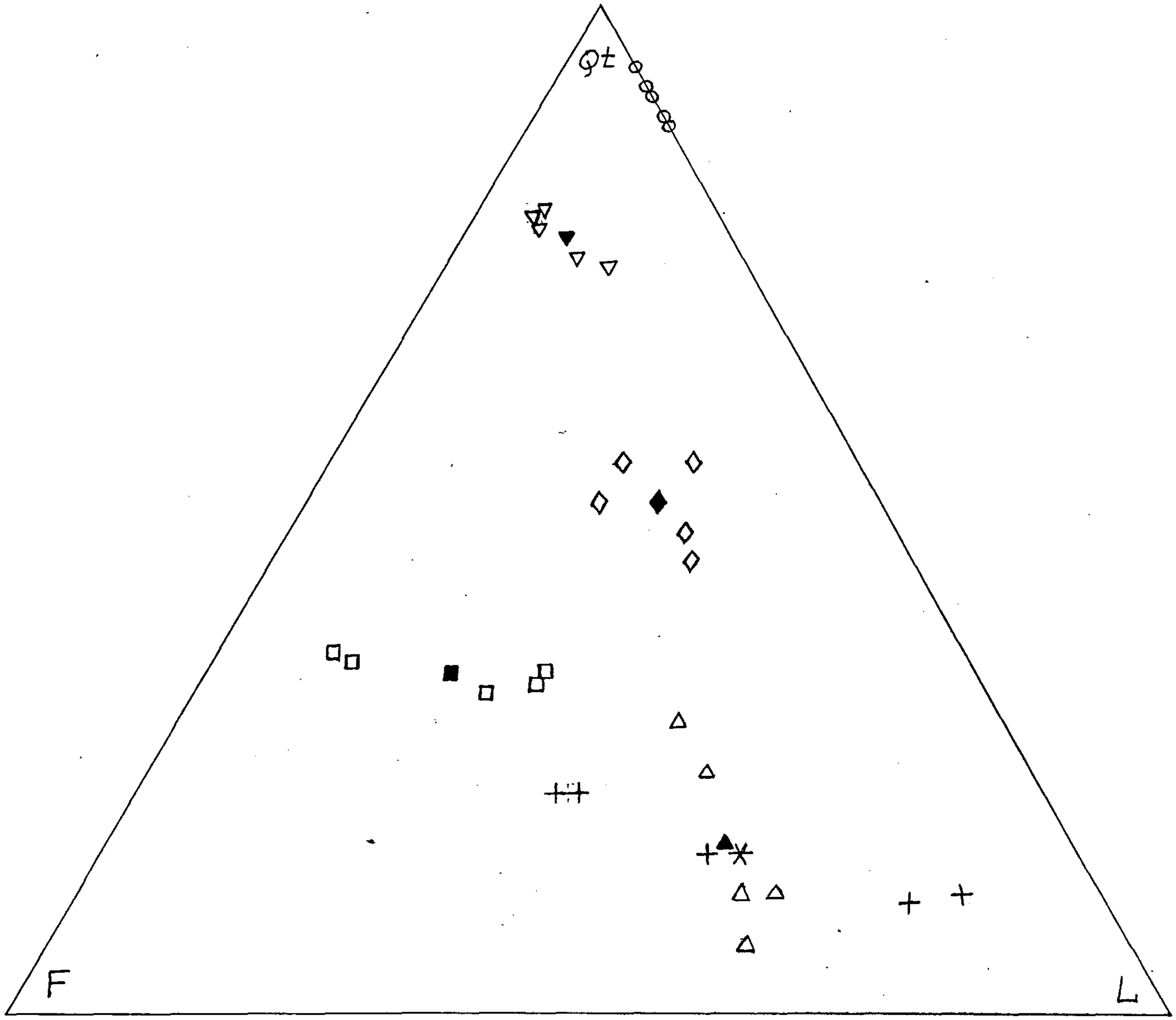


Figure 4. QtFL diagram (see Table 1 for grain types)
[points for individual samples open; points for means solid]

◇ Apache Wash succession

□ Livingston Hills succession

+ Ramsey Mine succession

△ Harquar succession

▽ Ranegras succession

○ Crystal Hills succession

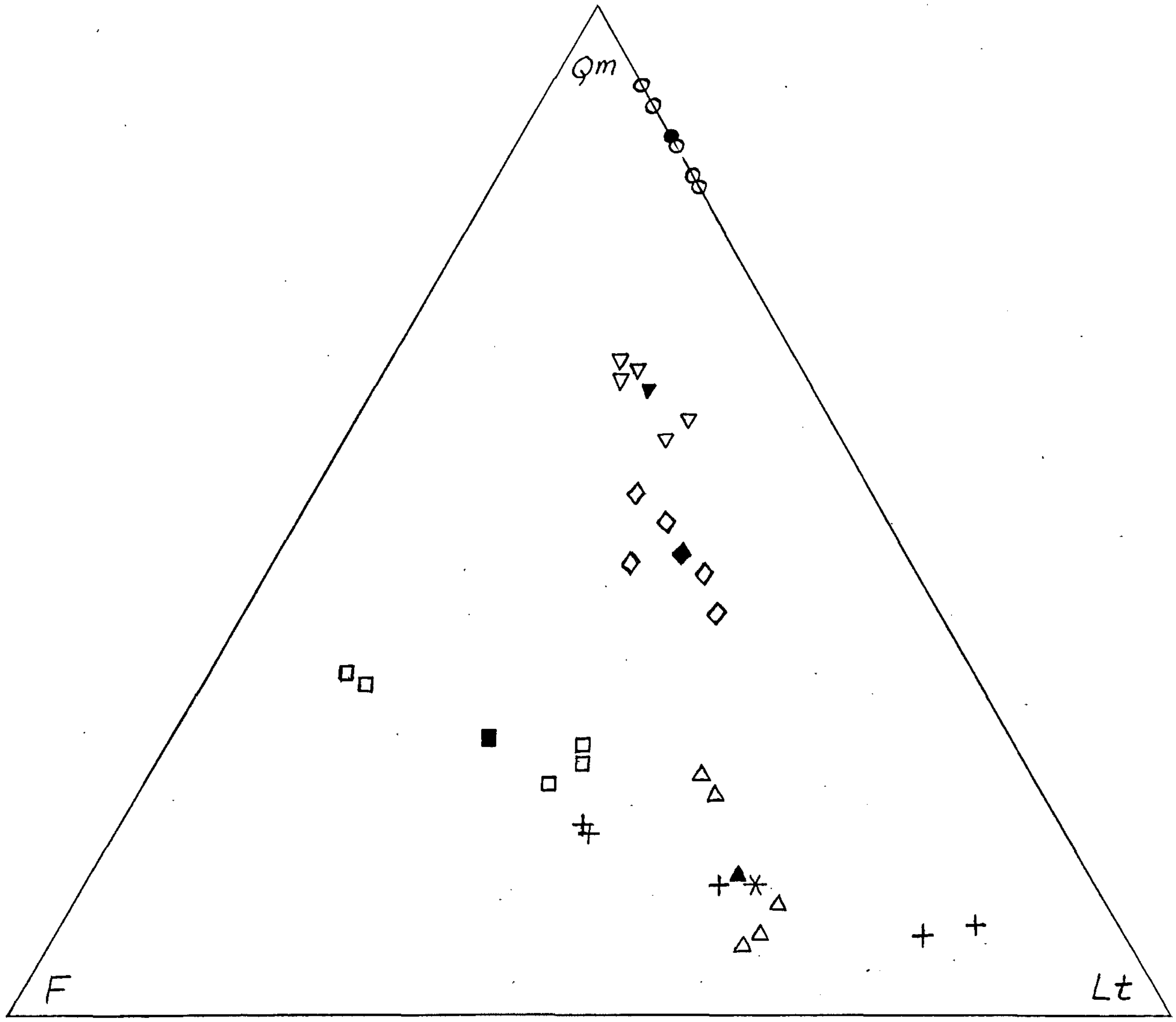


Figure 5. QmFLt diagram (see Table 1 for grain types)
[points for individual samples open; points for means solid]

◇ Apache Wash succession

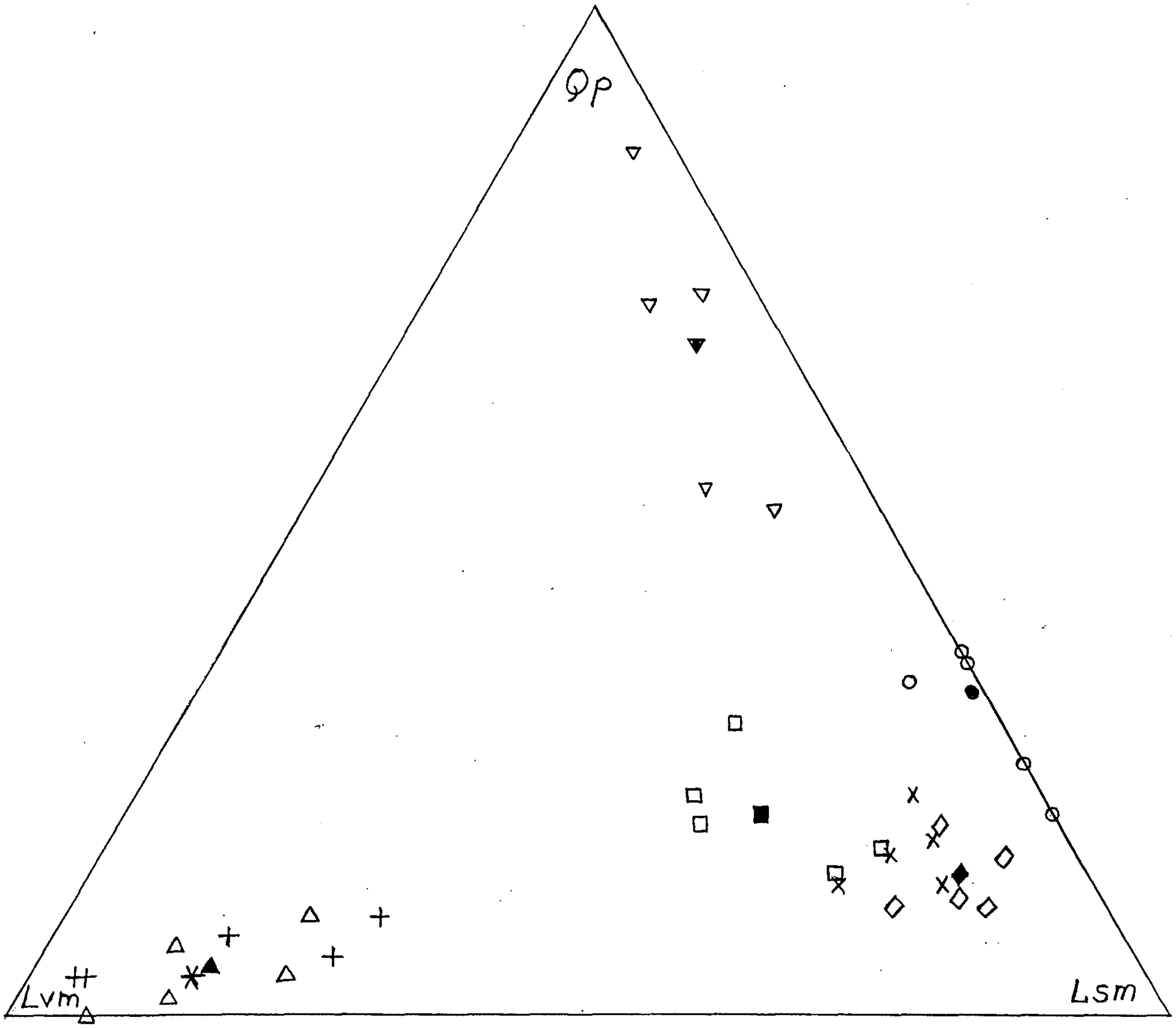
□ Livingston Hills succession

+ Ramsey Mine succession

△ Harquar succession

▽ Ranegras succession

○ Crystal Hills succession



[x = Apache Wash succession recalculated free of detrital limeclasts, Lc]

Figure 6. QpLvmLsm diagram (see Table 1 for grain types)
[points for individual samples open; points for means solid]

- ◇ Apache Wash succession
- □ Livingston Hills succession
- + Ramsey Mine succession
- △ Harquar succession
- ▽ Ranegras succession
- ○ Crystal Hills succession

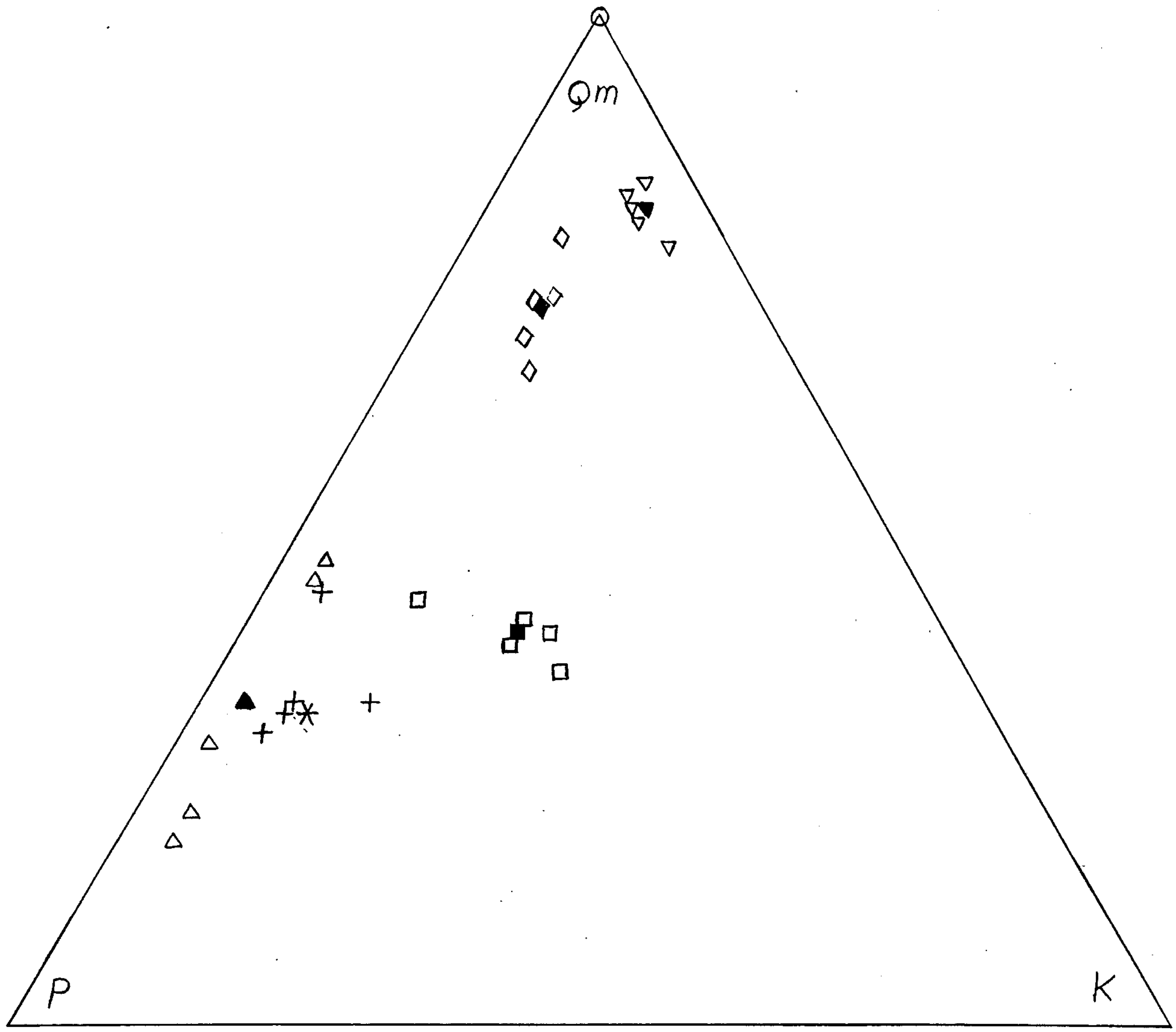


Figure 7. QmPK diagram (see Table 1 for grain types)
[points for individual samples open; points for means solid]

◇ Apache Wash succession

□ Livingston Hills succession

+ Ramsey Mine succession

△ Harquar succession

▽ Ranegras succession

○ Crystal Hills succession