New Mexico Bureau of Mines and Mineral Resources

Open-File Report 91

Basic Petrographic Data Compiled for Hydrogeologic Study of the San Juan Basin, Northwest New Mexico

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July, 1979

Contents

Illustrations

INTRODUCTION

Overview of Hydrogeologic Study

In July, 1972, the New Mexico Bureau of Mines and Mineral Resources undertook a study of the ground-water resources in the New Mexico portion of the San Juan Basin to determine the availability of water supplies for coal surface mining. The initial project was funded in part through a grant from the New Mexico Water Resources Research Institute and by contributions from El Paso Natural Gas Company, Peabody Coal Company, and Western Coal Company. The scope of the project was expanded in 1974 to include the entire water-resource/energy spectrum in the area, and the study was continued as a cooperative effort of the Bureau, the Water-Resource Division of the U.S. Geological Survey, and the New Mexico State Engineer's Office.

In the present study, the Bureau is responsible for characterizing the geologic framework of the Basin and helping evaluate the extent to which this framework controls the ground-water system(s) operative there. To accomplish this the Bureau part of the study has involved:

1. Preparation of maps showing evaluation of top (structure), depth to top, and total thickness for all potential aquifers in the Basin.
2. Construction of a series of geologic cross sections to show the position, structure, thickness, and lateral continuity of Jurassic and younger strata in the Basin.

3. Field measurement, description, and selective sampling of representative straitigraphic sections of major rock units in the basin.
4. Analyses of the petrography (texture, porosity, and composition) of major aquifers and selected confining layers in the Basin.

Purpose of This Report

Although much useful hydrogeologic information has already been compiled by both the U.S. Geological Survey and the Bureau, the project was scheduled to run for 5 years, and final reports will not appear before 1980. Presently there is considerable resource-development activity in the San Juan Basin, and the need for hydrogeologic information is urgent. To assure that interested parties have ready access to at least the basic data of our study prior to the completion of the final report, it was decided that a series of Open-File Reports be prepared: the Survey would report the basic hydrologic data (well records and water chemistry) and the Bureau would give the basic geologic data. As outlined above, the Bureau's geologic effort has included surface and subsurface stratigraphic studies as well as various petrographic analyses. The purpose of this report is to release the results of the Bureau's petrographic study of the major aquifers in the San Juan Basin. Results of the subsurface stratigraphic study are reported in OF-89 (Stone and Mizell, 1978). Measured section descriptions are presented in OF-90 (Stone, 1979).

The San Juan Basin

The San Juan Basin is a Laramide depression at the eastern edge of the Colorado Plateau. The Basin covers about 30,000 mi^2 in northwestern New Mexico and southwestern Colorado (figure 1). Structural relief in the Basin amounts to about 6,000 ft; monoclines are the most prominent structures. Faults are known to be abundant along the southern margin of the Basin, but the occurrence of soft shales at the surface of much of the area hinders field recognition of faulting outside this area.

The hydrogeologic study of the San Juan Basin has focused mainly on the Morrison Formation (Jurassic) and overlying rock units because 1) except in a narrow belt near the outcrop, underlying deposits are generally too deep in most of the Basin to be economically useful as aquifers, 2) the hydrologic and geologic characteristics of the deeper units are too poorly known, and 3) present energy development, specifically uranium mining, directly involves no units deeper than the Morrison. The stratigraphic framework and nomenclature of the deposits of interest in the present study are given in figure 2. In general, this sequence of deposits reflects a shift from largely continental deposition in Triassic and Jurassic times, to alternating marine/nonmarine shorezone deposition, continental deposition in Tertiary time.

More specifically, the Entrada-Todilto-Sumerville-Zuni/Bluff/Cow-Springs interval probably represents deposition in various desert environments (eolian dune field, inland sebkha,

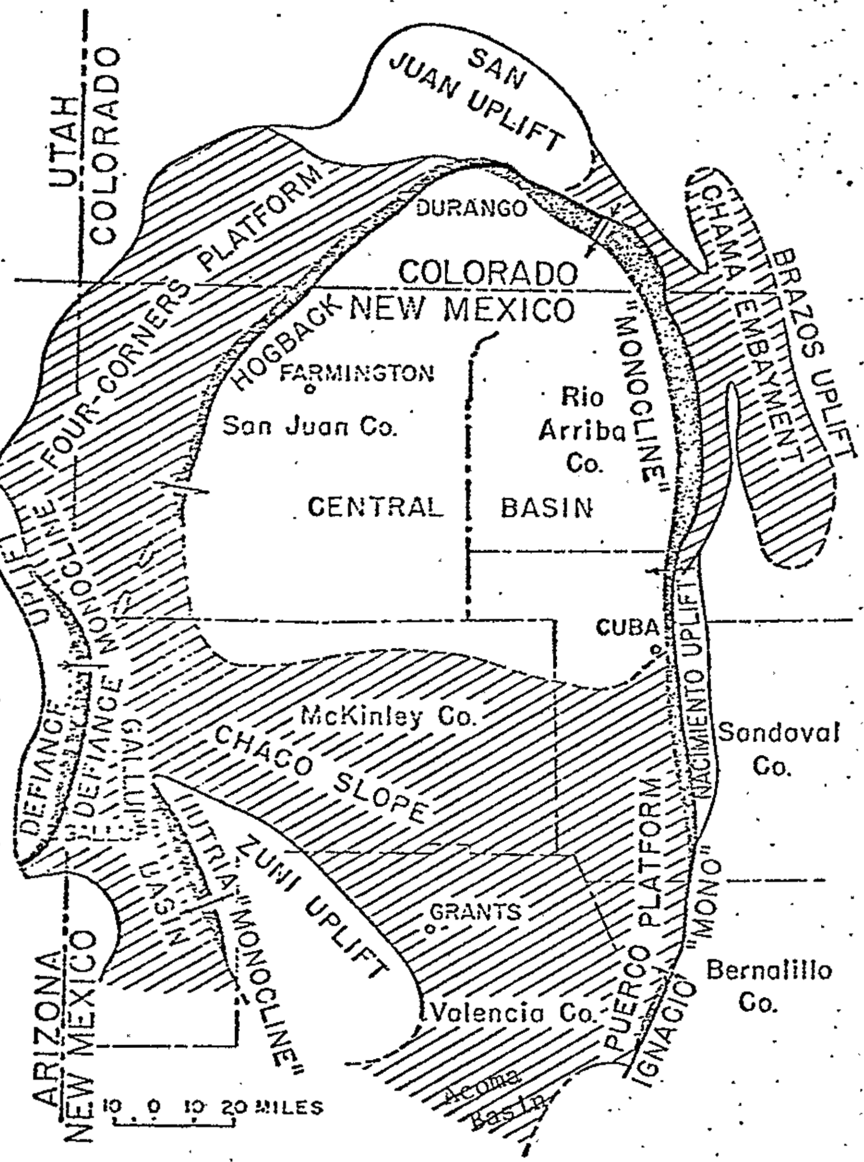

Figure 1. Location and structural elements of the San Juan Basin (as modified from Kelley, 1951, by Beaumont and others, 1976).

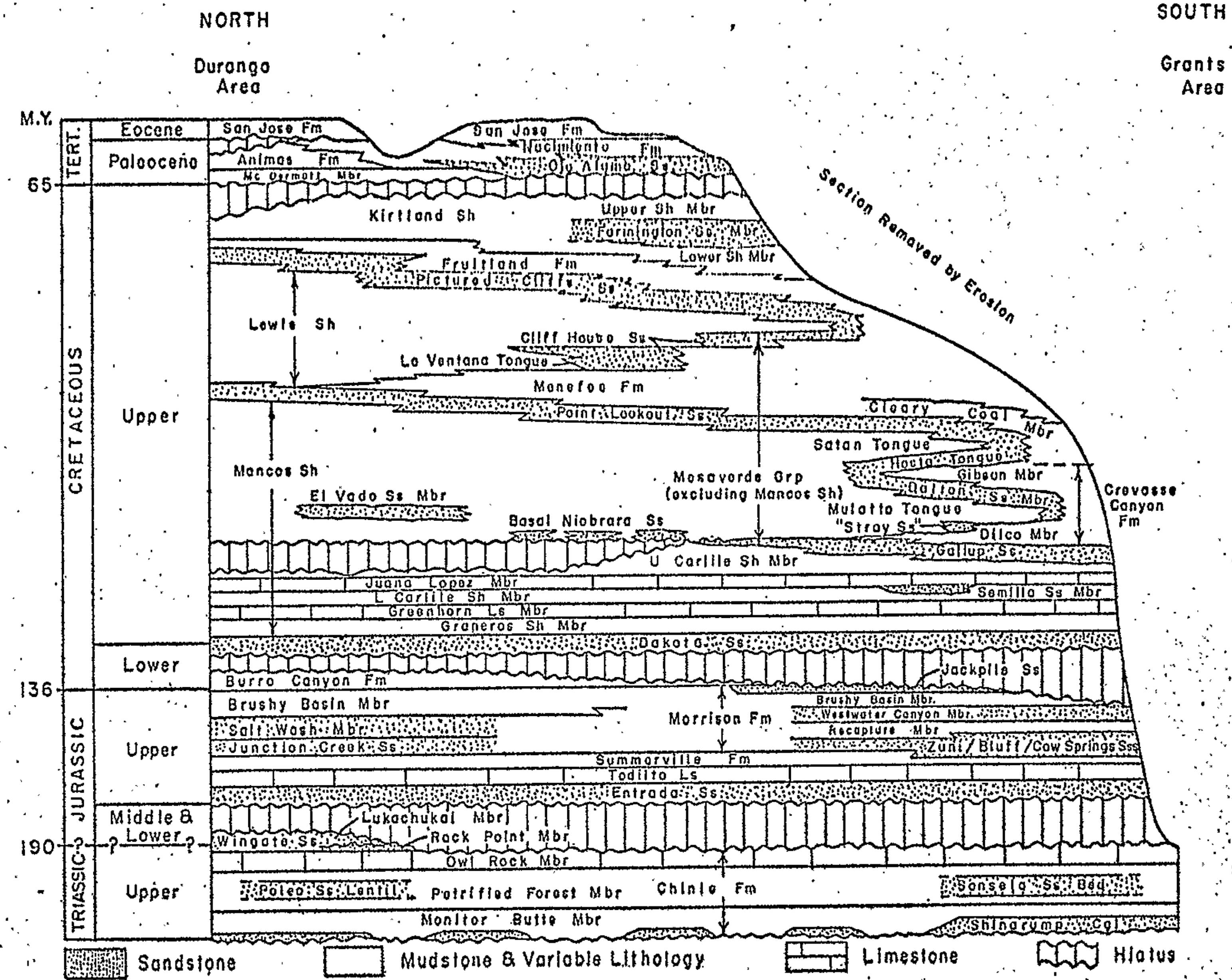

Figure 2. Time-stratigraphic framework and nomenclature, Triassic through Tertiary, San Juan Basin (modified from Molenaar, 1977).

lake). The Morrison Formation represents deposition under wetter conditions, perhaps alternating meandering/braided fluvial stream systems. The Dakota Sandstone records the initial invasion of this portion on North America by the vast Cretaceous seaway which extended from the Artic Ocean to the Gulf of Mexico some 135 million years ago. The Mesaverde Group of the San Juan Basin records the alternating transgressive/regressive shorezone deposition that characterized this sea. Transgressions are represented by the Dakota Sandstone, Borrego Pass Lentil of the Crevasse Canyon Formation, Hosta Tongue of the Point Lookout Sandstone, and the Cliff House Sandstone. Regressions are documented by the Gallup Sandstone, Dalton Sandstone Member of the Crevasse Canyon Formation, the main body of the Point Lookout Sandstone, and the Pictured Cliffs Sandstone. With the final retreat of the sea, marked by the deposition of the Pictured Cliffs Sandstone, nonmarine conditions returned and prevailed throughout Plaeocene and Eocene time. To date no Oligocene deposits have been found in the Basin proper, suggesting they have been subsequently eroded or that the modern erosional cycle was initiated as early as Oligocene time.

Previous Petrographic Work

Although it is beyond the scope of this report to review all the petrographic work done over the years on post-Triassic rocks of the San Juan Basin, it is appropriate to identify for the reader selected references which also contain textural or mineralogic data. Most of the works cited contain excellent bibliographies which give additional references.

The most comprehensive petrographic work on the sedimentary rocks covered by the present hydrogeologic study was done by Willard (1954 and 1964), based on samples from outcrops in the western part of the San Juan Basin. His studies included the Chinle Formation and overlying units through the Satan Tongue of the Mancos Shale as well as the Chuska Sandstone. The proceedings of the Grants Uranium Region Field Conference (chaired by Kelley, 1963) includes numerous articles on the ore mineralogy of the Morrison Formation. A report on the Morrison Formation by Sears and others (1974) includes a section on petrographic analyses. Owen (1963) presented results of textural and mineralogic analyses of the Dakota Sandstone. Sabins (1963) reported on various petrographic characteristics of the Gallup Sandstone. Shetiwy (1978) and Mannhard (1976) gave petrographic data for the Point Lookout Sandstone and La Ventana Tongue of the Cliff House Sandstone (respectively) along the eastern edge of the Basin. Dilworth's (1960) report on the Farmington Sandstone Member of the Kirtland Shale includes a section on petrography. Powell (1972) reported on the petrography of the Ojo Alamo Sandstone. Brown (1976) gave textural and mineralogic data for the Nacimiento and San Jose Formations near Aztec.

Using This Report

Textural data are given in table 1 and mineralogic data are given in table 2. In both of these tables data are arranged by stratigraphic unit, facilitating the search for data on a <u>unit</u> of interest. To determine what data are available for a given <u>area</u> of interest, simply scan the "Location" column in these tables.

For a visual presentation of the data see figures 3, 4, 5, and 6. Points on these plots are identified by a number which is the "analysis number" listed in the first column of each of the tables. In the case of the mineralogic data, an average composition has been determined for each of the three groups of analyses plotted (Tertiary, Cretaceous, and Jurassic/ Triassic).

Acknowledgements

Most of the textural (mechanical) analyses were performed by three geoscience graduate students at New Mexico Tech while Bureau research assistants under by supervision: Henry L. Fleischhauer, Jr., Robert C. Brod, and Scott K. Anderholm. Other textural analyses reported here were conducted for and are reported in theses done in conjunction with the hydrogeologic study and supported by the Bureau. The identity of the analyst or thesis source is given for each sample (table 1). The thesis by Brod (1979, Hydrogeology and Water Resources of the Ambrosia Lake--San Mateo area, McKinley and Valencia Counties, New Mexico) was in final preparation as of this writing so was not included under References Cited.

Most of the mineralogical (thin-section) analyses presented here were made by Steven D. Craigg, a geoscience graduate student at New Mexico Tech, while serving as Bureau research assistant under my supervision. As with the textural

analyses, some results presented are drawn from Bureau-supported theses. Analysts/thesis sources are identified for each sample (table 2).

TEXTURAL ANALYSES

Objective and Samples Used

The objective of this portion of the petrographic study was to determine the general textural characteristics of the major and minor aquifers in the San Juan Basin. Owing to the size of the area and number of rock units involved, it was realized that a comprehensive textural analysis of any one aquifer, let alone all aquifers, was beyond the scope of the hydrogeologic study. It was nonetheless deemed useful to analyze a few samples of each aquifer to obtain actual textural parameters for descriptive purposes.

A total of 36 samples from 18 stratigraphic units was analyzed (table 1). This includes one to four samples of each aquifer. A conscious effort was made to analyze each member or rock type in formations having a wide range of lithologic characteristics. Although most samples represent aquifers, some confining beds were also analyzed.

Laboratory Procedures

In general, the procedures used in dissaggregating and sieving the samples, as well as the statistical parameters used to describe them, were those of Folk (1974). The fine fraction was further analyzed by pipette or hydrometer methods as outlined by Folk (1974), Krumbein and Pettijohn (1938), and Royse (1970). In the sieving, it was felt that a whole-

TABLE 1. Results of textural (mechanical) analyses of major aquifers, San Juan Basin.[1]

Anal. No.	Unit	A/S	Sample No.	Location (1/4,sec,T,R)	Size Fractions (Ø)-% by weight C <1	M 1-2	F 2-3	VF 3-4	S/C >4	Total	Mode Ø	Mode Verb	Median Ø	Median Verb	Mean Ø	Mean Verb	Sig	Sorting Sg	Sorting Verb	S/M Ratio
1	Tc	LF	SJR-69	NE,6,35N,30E	4.98	62.80	26.90	4.96	0.34	100.00	2.00	M	1.70	M	1.77	M	0.56		MW	293
2	Tsj	DB	AR-B	SW,24,31N,10W	59.09	26.65	7.28	2.07	4.90	99.99	1.00	C	0.88	C	1.07	M	0.97		M	19.4
3	Tsj	DB	2B-12	NW,28,32N,11W	69.19	11.8	4.83	2.11	7.05	99.98	1.00	C	0.61	C	0.77	C		1.05	P	13.1
4	Tn	DB	8-1	SW,28,30,13W	22.46	62.06	6.04	2.15	7.28	99.99	2.00	M	1.43	M	1.43	M		0.55	M	12.7
5	Tn	DB	2B-1	SE,28,32N,11W	40.36	35.89	8.72	2.03	13.00	100.00	1.00	C	1.27	M	1.60	M		1.10	P	6.7
6	Toa	SA	SJR-11	SW,28,29N,12W	8.94	40.50	24.75	5.73	20.08	100.00	1-2	M	2.02	F	2.51	F	1.36	1.44	P	4.0
7	Toa	LF	SJR-14	SW,28,29N,12W	Agg	13.58	40.59	39.29	6.54	100.00*	3.00	F	2.90	F	2.90	F	1.60		VP	14.3
8	Toa	SA	SA-1	SE,33,26N,1E	9.76	40.55	18.54	5.91	25.24	100.00	1-2	M	1.99	M	2.56	F	1.41	1.52	P	3.0
9	Kk(f)	LF	SJ2-4-1	SW,21,29N,13W	Agg	Agg	36.12	56.14	7.73	99.99*	3-4	VF	3.20	VF	NA	NA	NA		NA	11.9
10	Kk(f)	LF	SJ2-4-2c	SW,21,29N,12W	9.00	60.70	23.50	4.60	2.30	100.00	1-2	M	1.70	M	1.80	M	0.70		MW	42.5
11	Kpc	LF	SJ1W-3-2	SW,32,30N,15W	Agg	Agg	Agg	60.20	9.90	100.01*	3-4	VF	3.87	VF	3.97	VF	NA		NA	1.5
12	Kpc	LF	SJ1W-3-3	SW,32,30N,15W	Agg	Agg	Agg	57.44	42.56	100.00*	>4	VF	3.93	VF	3.98	VF	NA		NA	1.4
13	Kch	LF	SJR-68	SE,13,22N,13W	0.00	0.49	72.09	15.78	11.60	99.96	2-3	F	2.85	F	2.96	F		0.43	MW	7.6
14	Kmf	SA	BMS3-1	SW,20,19N,1W	?	7.80	66.10	9.28	16.82	100.00	2-3	F	2.50	F	2.83	F	1.45	1.0	P	5.0
15	Kmf	SA	BMS3-2	SW,20,19N,1W	?	9.05	65.89	5.98	19.08	100.00	2-3	F	2.25	F	3.08	VF	1.70	1.5	P	4.2
16	Kpl	LF	SJR-40	SE,5,29N,16W	0.00	5.86	83.73	8.88	5.17	100.00	2-3	F	2.60	F	2.57	F	0.39		W	19.1
17	Kcda	BB	BB-4	NW,14,14N,8W	0.18	1.95	63.24	23.97	10.68	100.02	2-3	F	2.50	F	2.67	F	1.03	0.25	P	8.4
18	Kmm	BB	BB-5	NW,20,13N,8W	0.18	2.18	48.05	34.55	15.04	100.00	2-3	F	2.50	F	2.83	F	1.16	0.50	M	5.7
19	Kg	LF	SJ3-5-3	NW,21,30N,19W	2.00	79.10	13.30	2.70	2.90	100.00	1-2	M	1.70	M	1.77	M	0.70		MW	33.5
20	Kg	LF	SJ3-6-1	NW,17,27N,19W	0.30	20.40	64.60	9.80	4.90	100.00	2-3	F	2.40	F	2.60	F	0.91		M	19.4
21	Kg	LF	SJ3-6-3	NW,17,27N,19W	0.20	8.00	71.20	13.80	6.80	100.00	2-3	F	2.60	F	2.69	F		0.54	M	13.7
22	Kg	LF	SJ3-6-7b	NW,17,27N,19W	0.53	27.60	62.80	4.60	4.50	100.00	2-3	F	2.30	F	2.33	F	0.99		M	21.2
23	Kd	LF	SJ3-2-3	NW,26,30N,20W	0.02	19.40	70.70	4.70	5.20	100.02	2-3	F	2.40	F	2.41	F	0.79		M	18.2
24	Kd	LF	SJ3-3-10	SE,34,28N,20W	1.30	76.00	14.50	2.90	5.30	100.00	1-2	M	1.70	M	1.83	M	0.92		M	17.9
25	Kd	BB	BB-6	SE,14,13N,10W	0.05	6.15	49.03	30.74	14.04	100.01	2-3	F	2.50	F	2.67	F	0.91	0.75	M	6.1
26	Jmb	LF	SJ3-3-4a	SE,34,28N,20W	0.70	13.60	71.30	8.50	6.00	100.00	2-3	F	2.50	F	2.51	F		0.47	MW	15.7
27	Jmw	BB	BB-7	SE,14,13N,10W	91.60	2.75	3.10	1.59	0.98	100.02	<1	VC-G	<1.00	VC-G	1.00	VC-G	1.26	1.00	P	101.1
28	Jmw	BB	BB-8	SE,14,13N,10W	38.30	44.54	12.07	2.75	2.32	99.98	1-2	M	1.00	C	1.17	M	0.83	0.75	M	42.1
29	Jms	LF	SJ3-1-10b	SW,14,30N,21W	1.10	15.70	52.70	27.00	3.40	99.90	2-3	F	2.50	F	2.66	F	1.11		P	28.4
30	Jb	BB	BB-9	SE,14,13N,10W	0.24	31.69	50.41	10.00	7.68	100.02	2-3	M	2.00	M	2.17	F	1.36	0.75	P-M	12.0
31	Js	LF	SJ3-1-7	SW,14,30N,21W	0.00	0.60	18.50	72.30	8.50	99.90	3-4	VF	3.40	VF	3.38	VF		0.48	MW	10.8
32	Js	LF	SJ3-1-8	SW,14,30N,21W	0.70	1.40	43.50	41.40	13.00	100.00	2-3	F	3.10	VF	3.18	VF		0.67	M	6.7
33	Jeu	LF	SJ3-1-3	SW,14,30N,21W	0.00	4.80	47.00	38.90	9.30	100.00	2-3	F	3.00	F	3.05	F		0.68	M	9.8
34	Jeu	BB	BB-10	SW,23,13N,10W	0.16	11.01	62.49	16.35	9.19	99.20	2-3	F	2.50	F	2.50	F	1.24	0.50	P-M	9.8
35	Jem	LF	SJ3-1-2	SW,14,30N,21W	0.00	0.03	14.40	73.10	12.40	99.93	3-4	VF	3.50	VF	3.50	VF		0.45	MW	7.1
36	Jem	BB	BB-11	SW,23,13N,10W	0.00	0.72	3.67	52.04	43.56	99.99	3-4	VF	3.50	VF	>4.00	SLT	1.88	2.25	P-EP	1.3
37	Trw	BB	BB-12	SW,23,13N,10W	0.34	72.35	17.94	2.64	6.73	100.00	1-2	M	1.50	M	1.67	M	1.19	0.25	M	13.9

[1] Anal. No.=analysis number. Units, Tc=Chuska Ss,. Tsj=San Jose Fm., Tn=Nacimiento Fm., Toa=Ojo Alamo Ss., Kk(f)=Farmington Ss. Mbr. of Kirtland Sh., Kpc=Pictured Cliffs Ss., Kch=Cliffhouse Ss., Kmf=Menefee Fm., Kpl=Point Lookout Ss., Kcda=Dalton Ss. Mbr. of Crevasse Canyon Fm., Kmm=Mulatto Tongue of Mancos Sh., Kg=Gallup Ss., Kd=Dakota Ss., Jmb=Brushy Basin Mbr. of Morrison Fm., Jmw=Westwater Canyon Mbr. of Morrison Fm., Jms=Salt Wash Mbr. of Morrison Fm., Jb=Bluff Ss., Js=Summerville Fm., Jeu=Upper Mbr. of Entrada Ss., Jem=Middle Mbr. of Entrada Ss., Trw=Wingate Ss., A/S=analyst/source (SA=Scott K. Anderholmn; BB=Brod, 1979; DB=Brown, 1979; LF=Henry L. Fleischhauer, Jr.). Size Fractions, Ø=phi, Grv=gravel, VC=very coarse sand, C=coarse sand, M=medium sand, F=fine sand, VF=very fine sand, S/C=silt and clay; these abbreviations also under Mode, Median, and Mean; Verb=verbal. Sorting, Sig=inclusive graphic standard deviation of Folk (1974, p.46), Sg=graphic standard deviation of Folk (1974, p. 45). Sg is used where specific size of the 95th percentile uncertain. Verbal sorting, EP=extremely poor, P=poor, M=moderate, NW=moderately well, NA=not applicable, S/M=sand/mud ratio. See figure 3 and Appendix for plots of textural data. Samples marked by "*" under Size Fractions contained appreciable amounts of aggregate and thus were not plotted. Additional data will appear in New Mexico Tech M.S. theses by S.K. Anderholm and S.D. Craigg.

phi sieve set was sufficient for general classification purposes. Samples were weighed to the nearest hundredth of a gram by means of a triple-beam or automatic balance.

Textural data were analyzed with the aid of a computer program which prints three sheets for each sample: a page giving the raw data (initial and final sample weights, size-class weights, class weight percentages, and cumulative weight percentages), another giving a cumulative curve and histogram plotted on the same set of axes, and a third page presenting statistical parameters computed for the sample. Information from sheets 1 and 3 of the computer printouts is summarized in table 1 so they are not reproduced here; however the computer plots for each sample are given in the Appendix.

Discussion of Results

Results of textural analyses were plotted or triangular diagrams having end members as follows: silt and clay, very fine and fine sand, and coarse and medium sand (figure 3). Two general populations of points are apparent on figure 3, one in the medium-coarse sand corner and one in the very fine-fine sand corner.

The coarser-grained population includes mainly rocks of Tertiary age, but three Cretaceous, rocks, two Jurassic rocks, and the only Triassic unit sampled also plotted there (see table 1 for detailed information). Most of these are fluvial in origin. The exception is analysis 21 representing the marine offshore-bar facies of the Gallup Sandstone, which is usually coarse. The finer-grained population includes

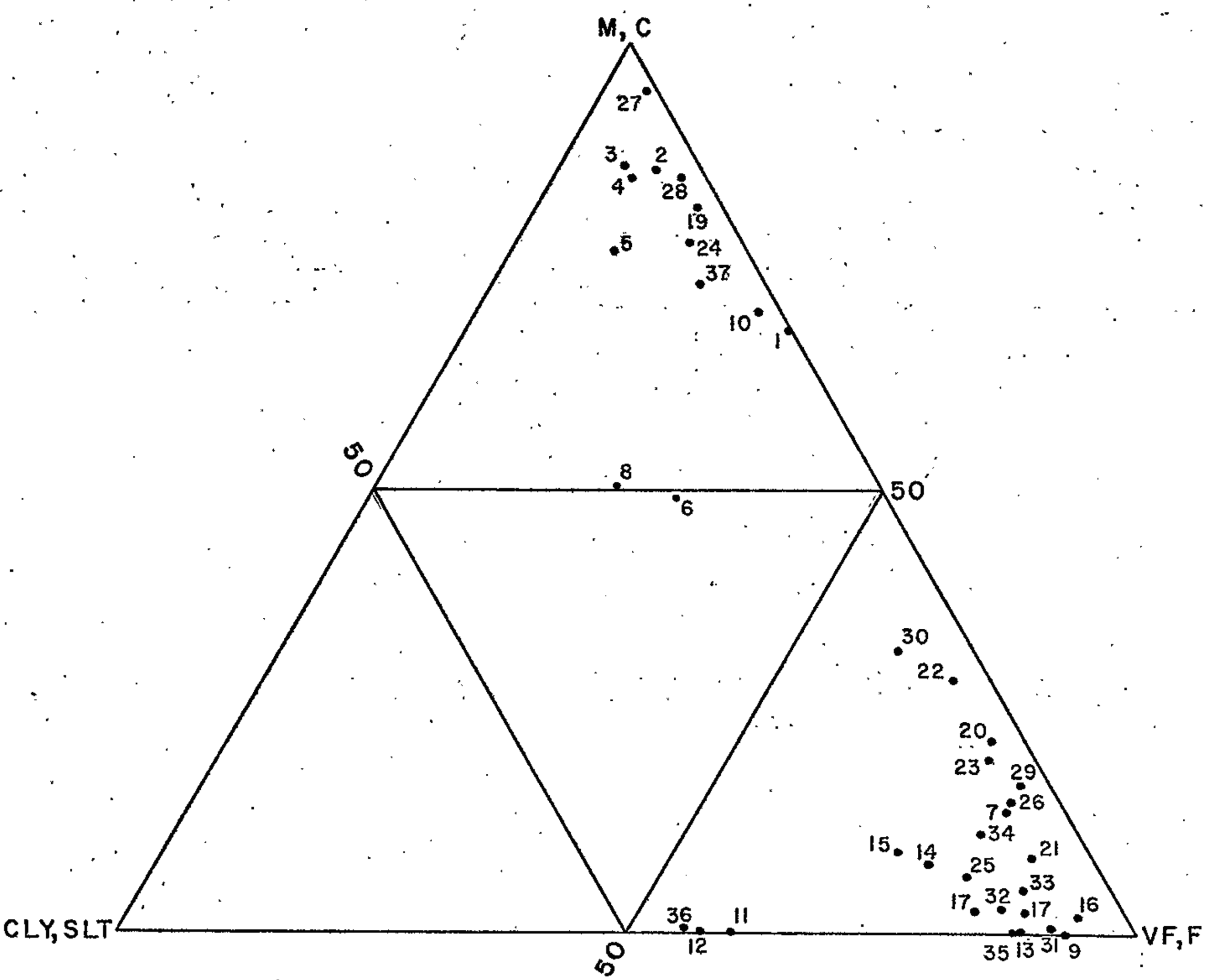

Figure 3. Texture of San Juan Basin aquifers. Samples identified by analysis numbers (table 1); 50% lines marked for reference. M,C = medium and coarse sand; VF,F = very fine and fine sand; CLY,SLT = clay and silt.

nearly equal numbers of Jurassic and Cretaceous rocks and a single sample of Tertiary rock. Two samples of Tertiary rock plotted midway between these populations, apparently because of an intermediate coarser sand fraction and relatively high mud content. The Jurassic rocks represent deposition in eolian dune, inland sebkha, or fluvial floodplain environments, whereas, the Cretaceous rocks represent various marine and nonmarine coastal environments of deposition. The Tertiary sample is of fluvial floodplain origin.

Much of the fine material reported in the analyses is secondary, that is, the product of diagenesis (and weathering in the case of outcrop samples). This is especially true in view of the feldspathic composition of the rocks (as shown in the following section) but also in view of the abundance of sand- to pebble-sized clasts of mud (rip up) which characterize most of the rocks studied. Both the feldspar and mud chips disintegrate to produce not only a finer median grain size than when deposited, but also an anomolously high mud content. Although this makes size analysis a poor tool for determining original depositional environment of these rocks, it does not preclude its use in obtaining useful textural parameters for the aquifers as they exist today.

MINERALOGICAL ANALYSES

Objectives and Samples Used

The main objective of the mineralogical analysis portion of the petrographic study was to determine the mineralogic characteristics of the major and minor aquifers in the San Juan Basin. A secondary objective was to learn the framework-matrix-cement-porosity relationships for these rocks. As in the textural study, it was realized that only a few samples could be analyzed. Nonetheless it was felt that the results would be useful, if only for descriptive purposes.

A total of 56 samples representing 20 rock units was analyzed (table 2). This involved one to six samples from each unit. As in the textural study, an attempt was made to analyze all major rock types or members within lithologically variable units.

Analytical Procedures

Thin sections were prepared by the Bureau preparation laboratory. Most required impregnation under vacuum.

Microscopic examinations were made with a Leitz polarizing microscope and mechanical stage. Point counts were recorded on two eight-item manual lab counters.

Analyses generally consisted of three steps: 1) examination of a hand specimen of the sample with a binocular microscope, 2) a general scan of the thin section with the polarizing microscope to provide familiarity with the mineralogy of the sample, and 3) point counting with the polarizing microscope and mechanical stage. During the general scan, such things as grain-size range, modal grain size, sorting, roundness, sphericity, elongation, textural maturity, grain contacts, and accessory minerals were noted. The point counting included two phases: 1) counting of 100 points to determine

TABLE 2. Results of mineralogic (thin section) analyses of major San Juan Basin aquifers.[1]

Anal. No.	Unit	A/S	Sample No.	Location (1/4,sec,T,R)	Whole Rock (%) Frmwk	Cem	Mtx	Por	Framework(%) Q	F	RF	Size Range	Texture Mo	Srt	RdnS	Sph	Elong	TM	Clas
1	Tc	SC	SJR-54	NE,6,35N,30E	70	25	3	2	76	23	1	Cslt-C	M	M	A-WR	P-E	VEL-VE	Sub	SA
2	Tsj	SC	SJR-48	NE,23,25N,4W	83	4	4	9	66	32	2	v-f-c	M	W	A-WR	P-E	VEL-VE	Sub	A
3	Tsj	DB	AR-B	SW,24,31N,10W	71	(10)		19	57	37	6	C-VC	VC	P-M	SA-R	F-G		Sub	A
4	Tsj	DB	6-7	SE,22,31N,10W	78	(6)		16	61	32	7	C-VC	VC	M-W	SA-R	G		Sub	A
5	Tn	SC	SJR-46	NW,12,20N,2W	84	2	6	8	61	31	8	Cslt-C	F	W	A-WR	P-E	VEL-VE	I	A
6	Tn	SC	SJR-50	NE,27,31N,11W	84	14	2	0	48	42	10	M-GrV	C	VP	SM-WR	P-E	VEL-VE	Sub	A
7	Tn	DB	6-3	NW,27,31N,10W	70	(18)		12	46	39	15	VC	VC	M	SA-Sr	F-G			A
8	Tn	DB	6-4	NW,27,31N,10W	38.5	(60)		1.5	91	6	3		C	M	SR	F		I	A
9	Tn	DB	6-5	SE,22,31N,10W	76	(9)		15	55	32	13	C	C	M-W	SR-R	G		Sub	A
10	Toa	SC	SJR-11	SW,28,29N,12W	89	3	5	3	54	29	17	Cslt-C	M+C	P	SA-WR	P-E	VEL-VE	I	LA
11	Toa	SC	SJR-14	SW,28,29N,12W	81	4	9	6	51	34	15	Cslt-C	F	VP	A-SR	P-G	VEL-E	I	LA
12	Ta	SC	SJ-1W-4B-1b	SW,24,30N,14W	85	10	3	2	73	18	9	Cslt-C	F/M	W	A-WR	P-E	VEL-VE	Sub	LA
13	Ta	SC	SJ-1W-4B-2d	SW,24,30N,14W	74	10	14	2	68	18	14	Cslt-VC	M	M	A-WR	P-E	VEL-VE	I	LA
	Average for Tertiary sandstone aquifers analyzed								62	29	9								
14	Kk(f)	SC	SJ-2-4-1	SW,21,29N,13W	82	6	9	3	80	17	3	VF-M	F	M	A-SR	P-G	VE-VEL	I	SA
15	Kk(f)	SC	SJ-2-4-2c	SW,21,29N,13W	77	6	7	10	64	28	8	VF-VC	M	P	A-R	P-G	VE-VEL	I	A
16	Kf	SC	SJR-59	(Navajo Mine)	73	3	23	1	81	12	7	CSLT-F	VF	W	A-SR	P-E	VE-VEL	I	SA
17	Kf	SC	SJR-64	(San Juan Mine)	63	31	4	2	67	26	7	Cslt-M	F	W	A-SR	P-E	VE-VEL	Sub-M	A/LA
18	Kpc	SC	SJ-1W-3-2	SW,32,30N,15W	69	7	19	5	74	25	1	Cslt-F	VF	VW	A-R	P-E	VE-VEL	I	A/SA
19	Kpc	SC	SJ-1W-3-6	SW,32,30N,15W	58	42	-	-	79	20	1	Cslt-F	VF	W	A-R	P-E	VE-VEL	Sup	SA
20	Kch	SC	SJR-68	SE,13,22N,13W	82	3	10	5	80	19	1	Cslt-M	M	W	SA-WR	P-G	VE-VEL	I	SA
21	Klv	SC	SJR-23	NW,16,19N,1W	83	6	3	8	83	13	4	Cslt-M	F	SA-R		P-E	VE-VEL	Sub	SA
22	Klv	SC	SJR-42	SE,19,19N,1W	76	21	2	1	84	13	3	Cslt-M	F	VW	A-R	P-G	VE-VEL	Sub	SA
23	Kmf	SC	SJR-4	NE,11,23N,1W	68	11	21	-	61	26	13	Cslt-F	VF	W	A-SA	P-G	VE-VEL	I	LA
24	Kmf	SC	SJR-5	SE?5,29N,16W	78	5	8	9	59	26	15	VF-C	M	M	SA-WR	P-E	VE-VEL	I	LA
25	Kmf	SC	SJ-1W-2B-34	SW,4,29N,16W	60	38	2	-	62	23	15	Cslt-M	F	M	A-WR	P-E	VE-VEL	Sub	LA
26	Kpl	SC	SJR-6	SE,5,29,16W	76	15	4	5	70	16	14	VF-C	M	M	SA-R	F-G	SE	Sub	A
27	Kpl	SC	SJR-7	SE,5,29,16W	78	12	4	6	67	20	13	VF-C	M	M	A-W	P-E	I	Sub	A
28	Kpl	SC	SJR-8	SE,5,29,16W	62	38	-	-	60	26	14	VF-C	M	M	A-R	F-E	I-SE	Sub	A
29	Kpl	SC	SJR-9	SE,5,29,16W	73	11	7	9	69	21	10	VF-C	M	MW	A-R	P-G	I	I	A
30	Kpl	SC	SJ-1W-1-2	NW,7,31N,16W	80	14	3	3	59	35	6	SLT-F	F	MW	A-SR	P-G	I	Sub	A
31	Kpl	BB	2B-16(1)	NW,15,13N,8W	61	5	32	2	57	29	12*	VF-M	F	W	SA	G-E	VE	I	LA
32	Kcda	BB	2B-7(2)	NW,14,14N,8W	67	16	13	4	64	31	5	SLT-C	F	W	SA	G-E	E	I	LA
33	Kmm	BB	2B-3(3)	NW,20,13N,8W	63	-	26	11	62	30	8	SLT-M	F	VW	SA	G	E	I	LA
34	Kg	SC	SJR-31	NW,[illegible],30N,19W	80	8	3	9	74	14	12	Cslt-F	VF	VW	SA-R	F-E	VE-VEL	Sub	LA
35	Kg	SC	SJR-34	NE,26,28N,20W	86	8	3	4	70	28	2	F-C	M	W	SA-WR	P-E	VE-VEL	M	LA
36	Kg	SC	SJR-41	NW,21,30N,19W	87	4	2	7	73	23	4	F-C	C	W	SA-WR	P-E	VE-VEL	Sub	LA
37	Kg	BB	1[illegible]-3(4)	SW,16,14N,9W	84	3	7	6	56	41	2*	SLT-C	M	W	A-SA	G	E	M	LA
38	Kd	SC	SJR-2	SE,36,21N,1W	89	6	3	2	78	19	3	VF-M	F	VW	SA-WR	P-E	VE-VEL	Sub	SA
39	Kd	BB	1A-16(5)	SE,14,13N,10W	84	4	6	6	57	42	1	VF-M	F	W	A-SA	G-E	E-EL	M	A
	Average for Cretaceous sandstone aquifers analyzed								69	24	7								
40	Jmj	SC	SJR-16	SW,27,15N,1w	85	0	3	12	86	13	1	VF-C	M	W	SR-WR	F-E	EL-VE	Sub	A
41	Jmb	SC	SJ3-3-4a	SE,34,28N,20W	83	9	3	5	73	21	6	Cslt-C	M	W	SR-WR	P-E	VEL-VE	M	A
42	Jmb	SC	SJ3-3-4b	SE,34,28N,20W	71	29	0	0	81	11	8	VF-C	M	VW	SR-WR	F-E	E-VE	Sup	SA
43	Jmb	SC	SJ3-3-8b	SE,34,28N,20W	83	4	4	9	75	17	8	VF-C	C	W	SR-WR	F-E	EL-VE	M	SA
44	Jmw	SC	SJR-18	SW,36,17N,1W	72	21	4	3	67	27	6	Cslt-C	M	W	SA-WR	P-E	VEL-VE	Sub	A
45	Jmw	SC	SJR-19	SW,36,17N,1W	84	5	5	6	69	29	2	Cslt-M	M	MW	SA-SR	F-E	EL-VE	I	A
46	Jmw	SC	~~SJR-20~~	~~SW,36,17N,1W~~	~~65~~	~~4~~	~~3~~	~~8~~	~~69~~	21	10	VF-C	~~M~~	~~W~~	~~SA-WR~~	~~P-E~~	~~EL-VE~~	Sub	LA
47	Jmw	SC	SJR-30	(Kermac Sec.30 Mine)	75	9	6	10	61	26	13	Cslt-VC	M&C	VP	A-WR	P-E	VEL-VE	I	LA
48	Jmw	BB	1A-12(6)	SE,14,13N,10W	76	6	8	10	45	47	8	F-C	M	M	SR	G	E-EL	I	A
49	Jms	SC	SJ3-1-10b	SW,14,30N,21W	80	11	2	7	82	13	5	VF-F	F	W	A-WR	P-E	VEL-VE	M	SA
50	Jb	BB	1A-8	SE,14,13N,10W	80	7	6	7	60	40	0	F-M	M	W	SA	G	E	M	A
51	Js	SC	SJ3-1-7	SW,14,30N,21W	76	17	2	5	80	19	1	VF-F	F	VW	SA-SR	F-E	VEL-VE	M	SA
52	Js	SC	SJ3-1-8	SW,14,30N,21W	78	14	2	6	81	18	1	Cslt-M	F	VW	SA-SR	F-E	VEL-VE	M	SA
53	Je	SC	SJ3-1-2	SW,14,30N,21W	83	11	1	5	78	18	4	Cslt-F	VF	VW	SA-WR	P-E	VEL-VE	M	SA
54	Je	SC	SJ3-1-3	SW,14,30N,21W	82	6	2	10	80	18	2	Cslt-M	VF+M	W	SA-WR	P-E	VEL-VE	M	SA
55	Je	BB	1A-4(7)	SW,23,13N,10W	70	19	0	11	66	30	4	VF-M	F	VW	SR	G-E	E	Sup	LA
56	Trw	BB	1A-1	SW,23,13N,10W	80	0	3	17	73	25	2	VF-M	M	W	SR	G-E	E-EL	M	A
	Average for Jurassic and Triassic sandstone aquifers analysed								72	23	5								

[1] Anal No. = analysis number. Unit abbreviations same as in Table 1. A/S = analyst/source (BB = Brod, 1979; DB = Brown, 1976; SC = Steven D. Craigg). Frmwk = framework, Cem = cement, Mtx = matrix, Por = porosity. Q = quartz pole, F = feldspar pole, RF = rock fragment pole (of Folk's, 1974, sandstone classification); * = does not total 100% so not plotted. C slt = coarse silt, VF = very fine sand, F = fine sand, M = medium sand, C = coarse sand, VC = very coarse sand, Grv = gravel. Mo = modal grain size. Srt = estimated sorting (Folk, 1974); VP = very poor, P = poor, M = moderate, MW = moderately well, W = well, VW = very well. Rdns = roundness (Krumbein and Sloss, 1956, Fig.4-9); A = angular, SA = subangular, SR = subrounded, R = rounded, WR = well rounded. Sph = sphericity (Krumbein and Sloss, 1956, Fig.4-9); P = poor, F = fair, G = good, E = excellent. Elong = elongation (Folk, 1965); VEL = very elongate, EL = elongate, SEL = subelongate, I = intermediate, SE = subequant, E = equant, VE = very equant. TM = textural maturity (Folk, 1974); I = immature, Sub = submature, M = mature, Sup = super mature. Clas = classification (Folk, 1974); A = arkose, LA = lithic arkose, SA = subarkose. See Figures 4, 5, and 6 for plots of framework composition.

the relative abundance (percentage) of framework, cement, matrix, and porosity and 2) continued counting, ignoring everything but framework grains, until a total of 300 framework points had been covered to determine the mineralogy of the framework of the sample. An attempt was made to keep the spacing between points and rows of points appropriate for the grain size of the sample. This was controlled by selecting the appropriately knotched knob for advancing the X and Y position of the mechanical stage the desired distances. Results were grouped according to three categories as used in Folk's (1974) sandstone classification: quartz, feldspar, and rock fragments. Analyses were then plotted on triangular diagrams having these categories as poles, and the samples were classified according to Folk (1974). For clarity, the thin-section data are presented in three separate figures: figure 4 presents data for Tertiary rocks, figure 5 shows data for Cretaceous rocks, and figure 6 gives data for the Jurassic and Triassic rocks. Averages are indicated by the diamond-shaped points.

Discussion of Results

A comparison of figures 4, 5, and 6 leads one to conclude that the mineralogy of the aquifers of the San Juan Basin is quite similar and, regardless of age, they are arkosic. Based on the relatively small number of samples analyzed, the Tertiary units are mainly arkose-lithic arkose, whereas, the Cretaceous, Jurassic and Triassic rocks are fairly equally divided among the arkose, lithic arkose, and subarkose classifications.

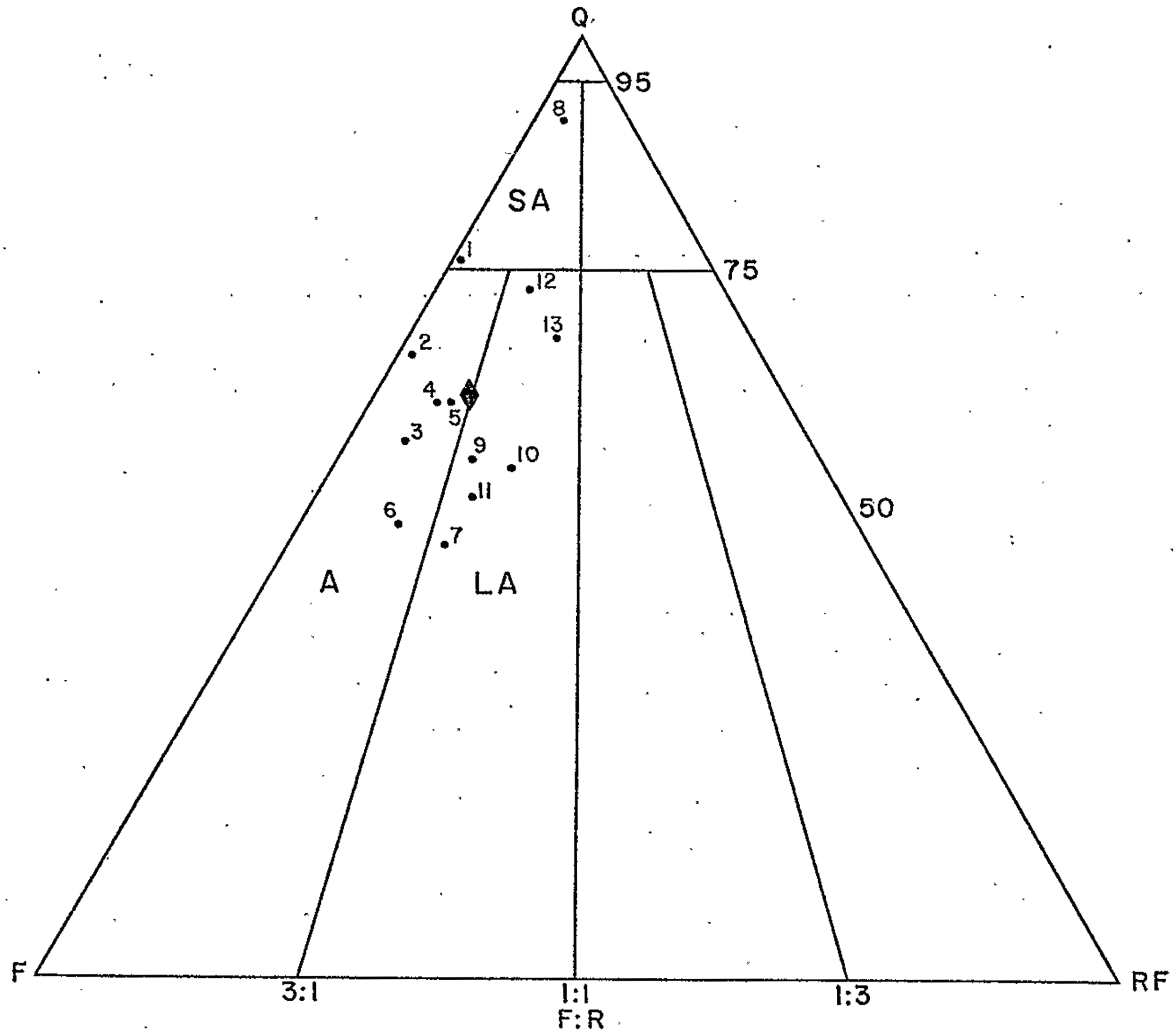

Figure 4. Composition of Tertiary sandstone aquifers, San Juan Basin. Samples identified by analysis numbers (table 2); average shown by diamond. Q = quartz, F = feldspar, RF = rock fragments, F:R = feldspar to rock fragment ratio, SA = subarkose, A = arkose, LA = lithic arkose (Folk, 1974); selected quartz percentages marked for reference.

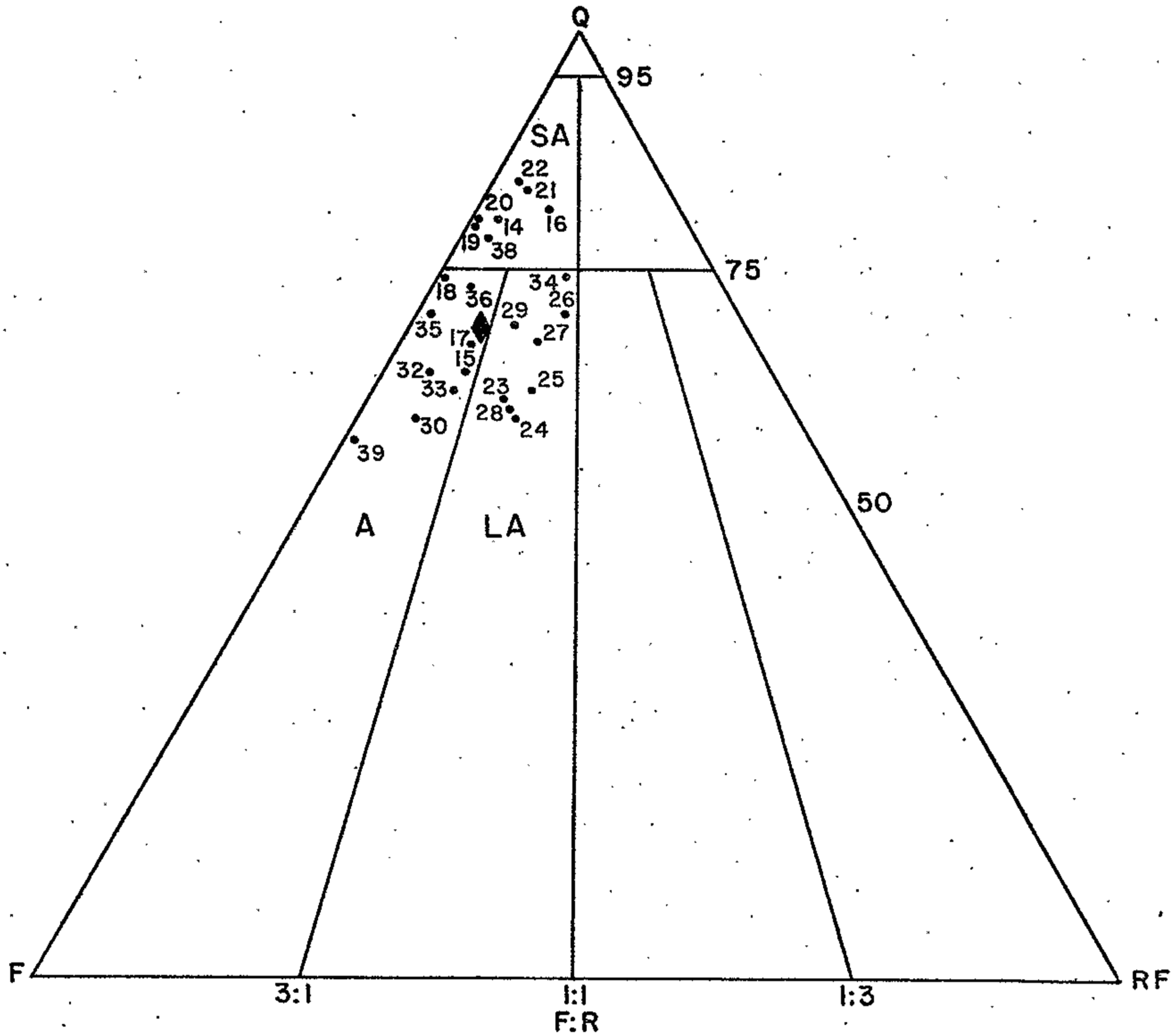

Figure 5. Composition of Cretaceous sandstone aquifers, San Juan Basin (see figure 4 for explanation).

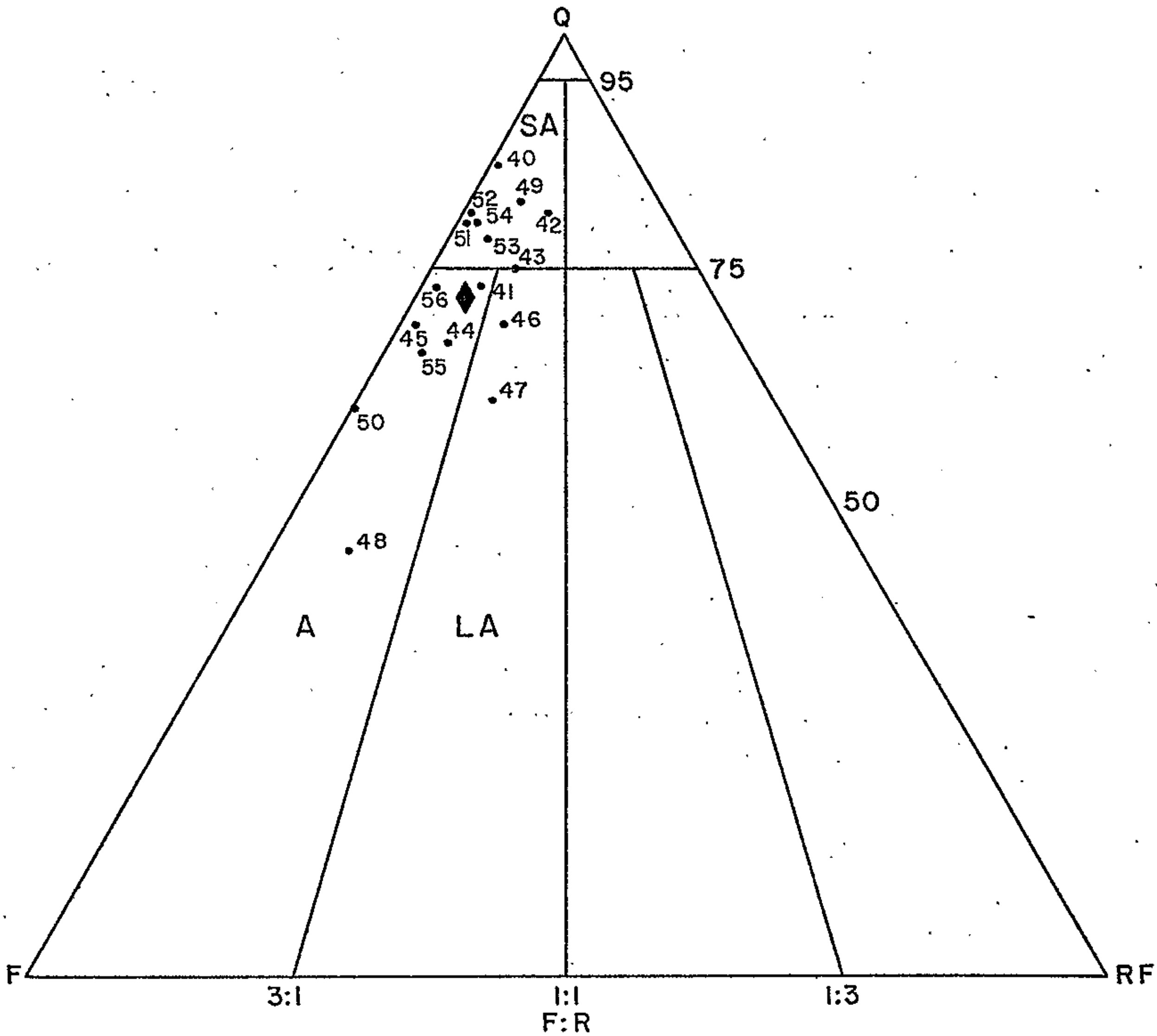

Figure 6. Composition of Jurassic and Triassic sandstone aquifers, San Juan Basin (see figure 4 for explanation).

As noted under "Textural Analyses" above, diagenesis and weathering have no doubt reduced the amount of feldspar which originally occurred as framework grains. This feldspar presently shows up in the samples as mud and is counted with the matrix rather than the framework. As is generally the case, therefore, classifications given apply to the present rock rather than the original deposit. The compositions reported should nonetheless be useful for water-quality interpretations.

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APPENDIX
Computer Plots of Textural Data
(prepared by Scott K. Anderholm)

```
SJR-69

                                         WEIGHT(PERCENT)

        0         10        20        30        40        50        60        70        80        90        100
        I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

1.00    .****0
2.00    .***************************************************************    0
3.00    .***************************                                                                   0
4.00    .*****                                                                                              0
5.00    .*                                                                                                  0
```

```
AR-B

                                         WEIGHT(PERCENT)

        0         10        20        30        40        50        60        70        80        90        100
        I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

1.00    .**********************************************************0
2.00    .***************************                                                          0
3.00    .*******                                                                                     0
4.00    .**                                                                                            0
5.00    .*****                                                                                              0
```

2B-12

```
                                      WEIGHT(PERCENT)
         0        10        20        30        40        50        60        70        80        90       100
         I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

 1.00    .*******************************************************************O
 2.00    .*****************                                                                     O
 3.00    .*****                                                                                      O
 4.00    .**                                                                                           O
 5.00    .*******                                                                                          O
```

8-1

```
                                      WEIGHT(PERCENT)
         0        10        20        30        40        50        60        70        80        90       100
         I.... ....I.........I.........I.........I.........I.........I.........I.........I.........I.........I

 1.00    .*********************O
 2.00    .**************************************************************                      O
 3.00    .******                                                                                    O
 4.00    .**                                                                                          O
 5.00    .*******                                                                                            O
```

```
2B-1

                                      WEIGHT(PERCENT)

          0        10        20        30        40        50        60        70        80        90       100
          I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

  1.00    .***************************************O
  2.00    .*************************************                                       O
  3.00    .*********                                                                            O
  4.00    .**                                                                                     O
  5.00    .*************                                                                                      O
```

```
SJR-11

                                      WEIGHT(PERCENT)

          0        10        20        30        40        50        60        70        80        90       100
          I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

  1.00    .********O
  2.00    .****************************************        O
  3.00    .*************************                                                O
  4.00    .******                                                                         O
  5.00    .********************                                                                               O
```

```
SA- 1
                                    WEIGHT(PERCENT)
          0         10        20        30        40        50        60        70        80        90        100
          I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I
 1.00     .*********0
 2.00     .*****************************************         0
 3.00     .*******************                                                   0
 4.00     .******                                                                      0
 5.00     .*************************                                                                           0
```

```
SJ2-4-20
                                    WEIGHT(PERCENT)
          0         10        20        30        40        50        60        70        80        90        100
          I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I
 1.00     .*********0
 2.00     .*************************************************************        0
 3.00     .***********************                                                                      0
 4.00     .*****                                                                                             0
 5.00     .**                                                                                                  0
```

```
SJK-68

                                       WEIGHT(PERCENT)

          0         10        20        30        40        50        60        70        80        90        100
          I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

1.00      .
2.00      .*
3.00      .**********************************************************************0
4.00      .***************                                                                      0
5.00      .************                                                                                     0
```

```
BMS3-1

                                       WEIGHT(PERCENT)

          0         10        20        30        40        50        60        70        80        90        100
          I.. ......I.........I.........I.........I.........I.........I.........I.........I.........I.........I

1.00      .
2.00      .*******0
3.00      .*****************************************************************       0
4.00      .*********                                                                        0
5.00      .*****************                                                                                0
```

```
BMS3-2
                                                  WEIGHT(PERCENT)
            0         10        20        30        40        50        60        70        80        90        100
            I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

   1.00     .
   2.00     .********0
   3.00     .*******************************************************************        0
   4.00     .******                                                                           0
   5.00     .*******************                                                                                   U
```

```
SJR-40
                                                  WEIGHT(PERCENT)
            0         10        20        30        40        50        60        70        80        90        100
            I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

   1.00     .
   2.00     .*****0
   3.00     .**********************************************************************************    U
   4.00     .*********                                                                                    0
   5.00     .*****                                                                                             0
```

BB-4

```
                              WEIGHT(PERCENT)
        0         10        20        30        40        50        60        70        80        90        100
        I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

1.00    .*
2.00    .*0
3.00    .*************************************************************** 0
4.00    .************************                                                                0
5.00    .***********                                                                                        0
```

BB-5

```
                              WEIGHT(PERCENT)
        0         10        20        30        40        50        60        70        80        90        100
        I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

1.00    .*
2.00    .*0
3.00    .************************************************ 0
4.00    .***********************************                                                 0
5.00    .***************                                                                                    0
```

```
SJ3-5-3

                                                   WEIGHT(PERCENT)

          0         10        20        30        40        50        60        70        80        90        100
          I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

1.00      .*O
2.00      .******************************************************************************* O
3.00      .*************                                                                                O
4.00      .***                                                                                             O
5.00      .***                                                                                                O
```

```
SJ3-6-1

                                                   WEIGHT(PERCENT)

          0         10        20        30        40        50        60        70        80        90        100
          I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

1.00      .*
2.00      .********************O
3.00      .*****************************************************************                   O
4.00      .**********                                                                                    O
5.00      .*****                                                                                              O
```

SJ3-6-3

```
                                          WEIGHT(PERCENT)
          0         10        20        30        40        50        60        70        80        90        100
          I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I
 1.00     .*
 2.00     .*******0
 3.00     .***********************************************************************       0
 4.00     .**************                                                                              0
 5.00     .*******                                                                                          0
```

SJ3-6-7 b

```
                                          WEIGHT(PERCENT)
          0         10        20        30        40        50        60        70        80        90        100
          I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I
 1.00     .0
 2.00     .***************************0
 3.00     .***************************************************************                            0
 4.00     .*****                                                                                           0
 5.00     .****                                                                                                0
```

32

```
SJ3-2-3

                                                WEIGHT(PERCENT)
          0         10        20        30        40        50        60        70        80        90        100
          I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I
1.00      .*
2.00      .******************0
3.00      .***********************************************************************                  0
4.00      .*****                                                                                         0
5.00      .*****                                                                                              0
```

```
SJ3-3-10

                                                WEIGHT(PERCENT)
          0         10        20        30        40        50        60        70        80        90        100
          I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I
1.00      .0
2.00      .****************************************************************************0
3.00      .***************                                                                            0
4.00      .***                                                                                           0
5.00      .*****                                                                                              0
```

BB-6

```
                                           WEIGHT(PERCENT)
         0         10        20        30        40        50        60        70        80        90        100
         I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

 1.00    .*
 2.00    .*****0
 3.00    .*************************************************     U
 4.00    .*******************************                                                      U
 5.00    .**************                                                                                     U
```

SJ3-3-4a

```
                                           WEIGHT(PERCENT)
         0         10        20        30        40        50        60        70        80        90        100
         I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

 1.00    .0
 2.00    .**************U
 3.00    .***********************************************************************              U
 4.00    .********                                                                                     U
 5.00    .******                                                                                             0
```

```
BB-7
                                             WEIGHT(PERCENT)
             0         10        20        30        40        50        60        70        80        90        100
             I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

    1.00     .*******************************************************************************************O
    2.00     .***                                                                                           O
    3.00     .***                                                                                             O
    4.00     .**                                                                                                O
    5.00     .*                                                                                                  O
```

```
BB-8
                                             WEIGHT(PERCENT)
             0         10        20        30        40        50        60        70        80        90        100
             I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

    1.00     .*************************************O
    2.00     .*********************************************                                     O
    3.00     .************                                                                                 O
    4.00     .***                                                                                              O
    5.00     .**                                                                                                 O
```

SJ3-1-10b

```
                                          WEIGHT(PERCENT)
         0         10        20        30        40        50        60        70        80        90        100
         I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

 1.00    .0
 2.00    .****************0
 3.00    .*****************************************************                0
 4.00    .***************************                                                                      0
 5.00    .***                                                                                                 0
```

BB-9

```
                                          WEIGHT(PERCENT)
         0         10        20        30        40        50        60        70        80        90        100
         I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

 1.00    .*
 2.00    .*******************************0
 3.00    .**************************************************                               0
 4.00    .**********                                                                                 0
 5.00    .********                                                                                           0
```

```
SJ3-1-7

                                        WEIGHT(PERCENT)
          0         10        20        30        40        50        60        70        80        90        100
          I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

   1.00   .
   2.00   .O
   3.00   .******************O
   4.00   .************************************************************************                  O
   5.00   .*********                                                                                          O



SJ3-1-8

                                        WEIGHT(PERCENT)
          0         10        20        30        40        50        60        70        80        90        100
          I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

   1.00   .O
   2.00   .*O
   3.00   .******************************************** O
   4.00   .*****************************************                                             O
   5.00   .*************                                                                                      O
```

```
SJ3-1-3
                                             WEIGHT(PERCENT)
          0         10        20        30        40        50        60        70        80        90        100
          I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I
1.00      .
2.00      .****O
3.00      .***********************************************    O
4.00      .***************************************                                                   O
5.00      .*********                                                                                          O
```

```
BB-10
                                             WEIGHT(PERCENT)
          0         10        20        30        40        50        60        70        80        90        100
          I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I
1.00      .*
2.00      .**********O
3.00      .***************************************************************          O
4.00      .****************                                                                          O
5.00      .*********                                                                                          O
```

38

```
SJ3-1-2

                                        WEIGHT(PERCENT)

         0         10        20        30        40        50        60        70        80        90        100
         I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

1.00     .
2.00     .*
3.00     .*************0
4.00     .*************************************************************************               0
5.00     .************                                                                                       0
```

```
BB-11

                                        WEIGHT(PERCENT)

         0         10        20        30        40        50        60        70        80        90        100
         I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

1.00     .
2.00     .0
3.00     .***0
4.00     .****************************************************   0
5.00     .********************************************                                                       0
```

```
BB-12
                                              WEIGHT(PERCENT)
           0         10        20        30        40        50        60        70        80        90        100
           I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I
   1.00    .*
   2.00    .************************************************************************0
   3.00    .******************                                                                        0
   4.00    .***                                                                                         0
   5.00    .*******                                                                                             0
```