Rational Mineral Analyses, Computed from Complete Empirical Chemical Analysis in the Detection and Correction of Errors in Quantitative Analytical Geochemistry

A. C. SHEAD, University of Oklahoma, Norman

Errors are too common in quantitative chemical analysis. They are especially prevalent in geochemistry. Too much reliance is often placed in checking results and on summations of one hundred percent. The checking of results, unless obtained by radically different methods for the same determination, may merely denote consistency, while a satisfactory summation may conceal gross compensating errors. Washington's (15) little-known and neglected method is available for the detection of such defective results. This consists in the recalculation of a complete empirical quantitative chemical analysis to its corresponding rational counterpart—in geochemistry, to one expressed in terms of mineral composition. This amounts to converting an analysis expressed in terms of hypothetical chemical combinations, having no existence in reality, to the corresponding expression in terms of actual minerals having recognized chemical compositions and characteristic chemical and physical properties. Interpretations based on rational analyses are far more significant and reliable. The neglect of Washington's method stems from the fact that it was applied only to igneous rocks and has never been applied to sedimentary rocks to any significant extent. One purpose of this paper is to remedy this deficiency.

Checking of acceptable summations of both analytical types constitute strong evidence of satisfactory results. These cannot be realized unless the analyses are correct and the minerals in the rocks and soils have been correctly identified. Since the minerals in such samples are generally minute, micro methods must be employed in their identification. One of the more useful procedures involves the application of polarized light microscopy by means of the so-called petrographic microscope. Milner's (9) treatise on sedimentary petrography is the most recent reference work on this subject and contains the most comprehensive data to be found for mineral identification. The more recent instrumental methods are included. The appended "literature" contains references to other useful methods employed in this connection, though these may not be directly referred to in the text of this paper.

Table I contains the more useful factors required for conversion of the hypothetical chemical combinations of the empirical analyses to the actual mineral species of the rational equivalents.

TABLE I
Gravimetric Conversion Factors for Analytical Geochemistry

Sought	Found	Factor	Ratio
ALBITE **$NaAlSi_3O_8$**	Na_2O	8.45765	2(262.145) : 61.99
Al_2O_3 (in albite)	Na_2O	1.6445	101.94 : 61.99
Al_2O_3 (in albite)	$NaAlSi_3O_8$	0.19443	101.94 : 2(262.145)
SiO_2 (in albite)	Na_2O	5.81319	360.36 : 61.99
SiO_2 (in albite)	$Na_2O \cdot Al_2O_3 \cdot 6SiO_2$	0.6873	360.36 : 524.29
ANHYDRITE, $CaSO_4$	SO_3	1.70047	136.14 : 80.06
$CaCO_3$ (equivalent to anhydride)	SO_3	1.25006	100.08 : 80.06
CaO (equivalent to anhydride)	SO_3	0.7005	56.08 : 80.06
Gypsum (equivalent to anhydrite)	SO_3	2.15041	172.17 : 80.06
Gypsum (equivalent to anhydrite)	$CaSO_4$	1.2646	172.17 : 136.14
APATITE, $CaF_2 \cdot 3Ca_3P_2O_8$	P_2O_5	2.3675	1008.962 : 3(142.054)
$CaCO_3$ (equivalent to apatite)	P_2O_5	2.34605	10(100.08) : 3(142.054)
$CaCO_3$ (equivalent to apatite)	$CaF_2 \cdot 3Ca_3P_2O_8$	0.9920	10(100.08) : 1008.962
CaO (equivalent to apatite)	$CaF_2 \cdot 3Ca_3P_2O_8$	0.5558	10(56.08) : 1008.962
CaO (equivalent to apatite)	P_2O_5	1.3159	10(56.08) : 3(142.054)
F (in apatite)	$CaF_2 \cdot 3Ca_3P_2O_8$	0.03766	2(19.00) : 1008.962
F (in apatite)	P_2O_5	0.08916	2(19.00) : 3(142.054)
$CaF_2 \cdot 3Ca_3P_2O_8$	F	26.5516	1008.962 : 2(19.00)
P_2O_5	$CaF_2 \cdot 3Ca_3P_2O_8$	0.42237	3(142.054) : 1008.962
BAUXITE, $Al_2O_3 \cdot 2H_2O$	Al_2O_3	1.3534	137.97 : 101.94
Al_2O_3 (in bauxite)	$Al_2O_3 \cdot 2H_2O$	0.7388	101.94 : 137.97
H_2O (in bauxite)	Al_2O_3	0.35346	2(18.016) : 101.94
H_2O (in bauxite)	$Al_2O_3 \cdot 2H_2O$	0.26116	2(18.016) : 137.97
BRUCITE, $MgO \cdot H_2O$	MgO	1.4469	58.34 : 40.32
H_2O (in brucite)	MgO	0.3088	18.016 : 58.34
CALCITE, $CaCO_3$. See Handbooks			
DOLOMITE, $MgCO_3 \cdot CaCO_3$	MgO	4.5739	184.40 : 40.32
$CaCO_3$ (in dolomite)	MgO	2.48214	100.08 : 40.32

TABLE I (Continued)
Gravimetric Conversion Factors for Analytical Geochemistry

Sought	Found	Factor	Ratio
CaO (in dolomite)	MgO	1.39087	56.08 : 40.32
CO_2 (in dolomite)	MgO	2.18006	2(44.00) : 40.32
GYPSUM, $CaSO_4 \cdot 2H_2O$	SO_3	2.1505	172.17 : 80.06
$CaCO_3$ (equivalent to gypsum)	SO_3	1.25006	100.08 : 80.06
CaO (equivalent to gypsum)	SO_3	0.7005	56.08 : 80.06
$CaSO_4$ (equivalent to gypsum)	SO_3	1.70047	136.14 : 80.06
$CaSO_4$ (in gypsum)	$CaSO_4 \cdot 2H_2O$	0.7948	136.14 : 172.17
H_2O (in gypsum)	$CaSO_4 \cdot 2H_2O$	0.2092	2(18.016) : 172.17
H_2O (in gypsum)	SO_3	0.45006	2(18.016) : 80.06
KAOLINITE, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	Al_2O_3	2.53178	258.09 : 101.94
Al_2O_3 (in kaolinite)	$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	0.39498	101.94 : 258.09
SiO_2 (in kaolinite)	$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	0.46542	2(60.06) : 258.09
SiO_2 (in kaolinite)	Al_2O_3	1.1783	2(60.06) : 101.94
H_2O (in kaolinite)	$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	0.1399	2(18.016) : 258.09
H_2O (in kaolinite)	Al_2O_3	0.35346	2(18.016) : 101.94
LIMONITE, $2Fe_2O_3 \cdot 3H_2O$	Fe_2O_3	1.1693	373.408 : 2(159.68)
H_2O (in limonite)	$2Fe_2O_3 \cdot 3H_2O$	0.14469	3(18.016) : 373.408
H_2O (in limonite)	Fe_2O_3	0.16923	3(18.016) : 2(159.68)
MARCASITE, FeS_2	Fe_2O_3	1.5025	2(119.26) : 159.68
MARCASITE, FeS_2	S	1.8708	119.96 : 2(32.06)
ORTHOCLASE, $KAlSi_3O_8$	K_2O	5.90806	2(278.25) : 94.20
ORTHOCLASE, $K_2O \cdot Al_2O_3 \cdot 6SiO_2$	K_2O	5.90764	556.50 : 94.20
Al_2O_3 (in orthoclase)	K_2O	1.08216	101.94 : 94.20
SiO_2 (in orthoclase)	K_2O	3.82547	6(60.06) : 94.20
SiO_2 (in orthoclase)	$KAlSi_3O_8$	0.6475	6(60.06) : 278.25
PYRITE, FeS_2 (See marcasite)			
PYROLUSITE, MnO_2	MnO	1.22557	86.93 : 70.93
SIDERITE, $FeCO_3$	FeO*		
CO_2 (in siderite)	FeO*		

*See Handbooks.

The following identifies the rocks analyzed by Shead (10), as listed according to the serial numbers in the publication cited. The capital letters preserve the sequence, in alphabetical order, in Table II.

Sandstones

A 262. Sand barite rosettes, "Rock Roses", a sandstone impregnated with barite, $BaSO_4$.

B 231. Duncan-Lone Wolf calcareous sandstone. A quartz, SiO_2 sandstone with calcite cement.

C 232. Duncan-Lone Wolf gypsiferous sandstone. Mostly a quartz, SiO_2-gypsum, $CaSO_4 \cdot 2H_2O$ mixture.

D *52.* Gypsite, an impure loosely-consolidated gypsum, valued for "Land Plaster" in agriculture.

Gypsums

E 26. Pure Medicine Lodge gypsum. Pure $CaSO_4 \cdot 2H_2O$. Remarkable for its near-chemical purity.

F 24. Medicine Lodge gypsum. Uncomplicated chemical composition. Utilized commercially.

G 23. Medicine Lodge gypsum-anhydrite. A $CaSO_4 \cdot 2H_2O$ — $CaSO_4$ rock.

Clay-Shale

H 246. Sylvan shale. Used in cement manufacture.

Limestones

I 113. Pure Short Creek oolitic limestone.

J 80. Pure Goodland limestone. Upper bed. Outcrops for over one hundred miles.

K 86. Impure siliceous Goodland limestone. Outcrops for over one hundred miles. Lower bed.

L 88. Siliceous Herington limestone. Has been quarried commercially.

M 140. Siliceous Winfield limestone. Has been quarried commercially.

N 94. Lost City ferruginous limestone.

O 261. Pure magnesian limestone. St. Clair "Marble". Quarried extensively for lime manufacture.

P 54. Impure siliceous magnesian Arbuckle limestone. Quarried extensively for concrete aggregate.

Q . Siliceous dolomite. Honey Creek sand dolomite. Useful for "rock wool" manufacture.

R 64. Pure Day Creek-Greenfield-Relay Creek dolomite. Name has been changed often.

S . Very pure Royer dolomite. Unusually complete chemical analysis.

Phosphate Rock

T 368. Cotton County phosphate rock. Complete analysis.

The above shows the wide variety of rock, the analyses of which are listed in Table II. Also to be noted is the number of minerals common to many of these rocks. It is remarkable that so many mineral species persist through all the changes from the most ancient primitive igneous rocks to the most recently formed soils.

General Remarks

The asterisk (*) denotes a calculated value in an empirical analysis and generally marks a correction in an original analysis to be found in a publication of Ham (5) or Shead (10) which also contains further details of exact location, description, uses, etc. of the rocks, named in Table II. All analyses, calculated factors of Table I, and conversions from empirical to rational analyses of samples found in Table II are by Shead (10).

All rational mineral analyses are calculated from the corresponding empirical analysis. Most corrections (*) involve hydrated minerals (kaolinite, gypsum, etc.) or mineral carbonates (siderite, magnesite, dolomite, calcite, etc.). Combined water is calculated from that in all the hydrates of the sample and carbon dioxide from that of all the carbonates. Such calculated values for combined water and for carbon dioxide in the empirical analysis appear to be more consistent and reliable than the corresponding determined values.

This stems from the fact that the hydrated minerals and carbonate minerals are calculated from more reliable determinations than those for the determinations of water and carbon dioxide and are independent of the latter determinations. This statement refers to determinations as usually carried out in analytical geochemistry. Values for water or carbon dioxide are seldom used for the calculation of rational mineral analysis, though exceptions do occur.

Conversion factors given in Table I are used for the calculation of the values recorded in Table II. These factors are no different in principle and use from those more familiar gravimetric factors to be found in current chemical handbooks. The ones in Table I, however, are calculated to tolerances required by the exacting standards of gravimetric chemical analysis. The few similar factors found in the geochemical literature are not so exacting. The special factors in Table I are not readily available elsewhere.

Very infrequently, in this paper, a value is calculated by difference. That is, the sum of all other values is subtracted from one hundred percent or a determined value close to one hundred percent, to afford a given figure. This is resorted to, only in case of an obvious misprint, typographical error, or other blemish in printing. It is justified by the axiom that "the whole is equal to the sum of all its parts".

Alumina, Al_2O_3 (corrected), refers to "crude" alumina less impurities usually included with it such as TiO_2, MnO, phosphates like apatite, etc. that may be present in the particular sample.

The following citations are intended to be references to microchemical and microscopical literature useful in the identification of minerals found in rocks and do not necessarily correspond to anything specifically mentioned in the text of this paper.

TABLE II

Conversion of Empirical Analyses, Above, to Rational Analyses, Below

Serial	A 262	B 231	C 232	D 52
Silica, SiO_2	45.13%	69.56%	66.91%	18.05 %
Alumina, Al_2O_3 (corrected)	.86%	%	—	2.45 %
Ferric Oxide, Fe_2O_3	0.96%	3.22%	1.16%	1.63 %
Magnesia, MgO	0.00%	0.29%	0.86%	0.00 %
Calcium Oxide, CaO	0.00%	14.38%	10.08%	25.75 %
Water (uncombined), H_2O	0.31%	0.91%	*0.64%	*2.49 %*
Water (combined), H_2O	*0.30%*	—	*5.75%*	*15.23 %*
Carbon Dioxide, CO_2	0.00%	*11.60%*	*1.87%*	*2.62 %*
Sulfur Trioxide, SO_3	17.87%	—	12.79%	*31.93 %*
Phosphorus Pentoxide, P_2O_5	trace	—	—	0.033%
Manganous Oxide, MnO	0.02%	—	—	nd
Barium Oxide, BaO	34.25%	0.00%	—	—
Total	99.70%	99.96%	100.06%	100.183%
Loss on Ignition, LOI	—	12.51%	8.26%	17.72 %
Quartz, SiO_2	44.12%	69.56%	66.91%	15.16 %
Kaolinite, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	2.18%	0.00%	—	6.20 %
Hematite, Fe_2O_3	0.96%	3.22%	1.16%	1.63 %
Dolomite, $MgCO_3 \cdot CaCO_3$	0.00%	1.33%	3.93%	0.00 %
Calcite, $CaCO_3$	0.00%	24.94%	—	5.95 %
Water (uncombined), H_2O	0.31%	0.91%	0.64%	2.45 %
Barite, $BaSO_4$	52.12%	0.00%	—	—
Apatite, $CaF_2 \cdot 3Ca_3P_2O_8$	trace	nd	—	0.08 %
Anhydrite, $CaSO_4$	0.00%	0.00%	0.00%	—
Gypsum, $CaSO_4 \cdot 2H_2O$	0.00%	0.00%	27.50%	68.67 %
Pyrolusite, MnO_2	0.02%	nd	nd	nd
Total	99.71%	99.96%	100.14%	100.14 %

Serial	E 26	F 24	G 23	H 246
Silica, SiO_2		0.02%	0.16%	58.57 %
Alumina, Al_2O_3 (corrected)	—	—	—	18.20 %
Ferric Oxide, Fe_2O_3		trace	trace	5.13 %
Magnesia, MgO		trace	trace	1.58 %
Calcium Oxide, CaO	32.41%	*32.45%*	*37.14%*	1.71 %
Sodium Oxide, Na_2O				0.63 %
Potassium Oxide, K_2O				4.05 %
Water (uncombined), H_2O	*0.43%*	*0.40%*	—	1.91 %
Water (combined), H_2O	*20.82%*	*20.74%*	10.03%	*4.53 %*
Carbon Dioxide, CO_2		0.12%		*2.83 %*
Sulfur Trioxide, SO_3	46.28%	46.11%	*53.01%*	0.00 %
Titania, TiO_2				0.71 %
Phosphorus Pentoxide, P_2O_5				0.22 %
Manganous Oxide, MnO				0.026%
Total	99.94%	99.84%	100.34%	100.096%
Quartz, SiO_2		0.02%	0.16%	24.36 %
Albite, $NaAlSi_3O_8$				5.33 %
Orthoclase, $KAlSi_3O_8$				23.93 %

TABLE II (Continued)

Kaolinite, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$				32.36 %
Hematite, Fe_2O_3			trace	5.13 %
Magnesite, $MgCO_3$			trace	3.30 %
Calcite, $CaCO_3$		0.27%		2.53 %
Water (uncombined), H_2O	0.43%	0.40%		1.91 %
Apatite, $CaF_2 \cdot 3Ca_3P_2O_8$				0.52 %
Pyrolusite, MnO_2				0.03 %
Rutile, TiO_2				0.71 %
Anhydrite, $CaSO_4$			52.26%	
Gypsum, $CaSO_4 \cdot 2H_2O$	99.51%	99.16%	47.92%	
Total	99.94%	99.85%	100.34%	100.11 %

Serial	I 113	J 80	K 86	L 88
Silica, SiO_2	0.16 %	1.01 %	27.48 %	5.44 %
Alumina, Al_2O_3 (corrected)	0.02 %	0.24 %	3.73 %	0.71 %
Ferric Oxide, Fe_2O_3	0.01 %	0.68 %	2.05 %	0.54 %
Ferrous Oxide, FeO	0.04 %	nd	nd	0.29 %
Magnesia, MgO	0.04 %	0.53 %	0.71 %	0.57 %
Calcium Oxide, CaO	55.90 %	54.57 %	35.11 %	51.20 %
Water (uncombined), H_2O	0.03 %	0.08 %	1.31 %	0.12 %
Water (combined)	0.01 %	trace	*1.32 %*	*0.25 %*
Carbon Dioxide, CO_2	*43.89 %*	*43.36 %*	*28.24 %*	40.95 %
Titania, TiO_2	0.00 %	0.00 %	0.13 %	trace
Phosphorus Pentoxide, P_2O_5	0.037%	0.037%	0.079%	0.028%
Manganous Oxide, MnO	0.01 %	0.044%	0.093%	0.09 %
Total	100.147%	100.551%	100.252%	100.188%
Quartz, SiO_2	0.14 %	0.73 %	23.08 %	4.60 %
Kaolinite, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	0.05 %	0.61 %	9.44 %	1.80 %
Hematite, Fe_2O_3	0.01 %	0.68 %	2.05 %	0.54 %
Siderite, $FeCO_3$	—.06 %	—	—	0.47 %
Dolomite, $MgCO_3 \cdot CaCO_3$	0.18 %	2.42 %	3.25 %	2.61 %
Calcite, $CaCO_3$	99.57 %	95.98 %	60.71 %	89.89 %
Water (uncombined), H_2O	0.03 %	0.08 %	1.31 %	0.12 %
Rutile, TiO_2	0.00 %	0.00 %	0.13 %	trace
Apatite, $CaF_2 \cdot 3Ca_3P_2O_8$	0.09 %	0.09 %	0.19 %	0.066%
Pyrolusite, MnO_2	0.01 %	0.05 %	0.11 %	0.11 %
Total	100.14 %	100.64 %	100.27 %	100.206%

Serial	M 140	N 94	O 261	P 54
Silica, SiO_2	8.14 %	*1.02 %*	0.075%	8.49 %
Alumina, Al_2O_3 (corrected)	0.17 %	0.87 %	0.000%	1.83 %
Ferric Oxide, Fe_2O_3	0.06 %	trace	0.065%	0.26 %
Ferrous Oxide, FeO	0.26 %	2.53 %	0.040%	0.44 %
Magnesia, MgO	0.63 %	3.81 %	5.86 %	6.38 %
Calcium Oxide, CaO	50.35 %	*48.10 %*	49.19 %	42.00 %
Water (uncombined), H_2O	0.08 %	trace	0.05 %	0.13 %
Water (combined), H_2O	0.06 %	*0.31 %*	0.00 %	*0.65 %
Carbon Dioxide, CO_2	*40.24 %*	*43.43 %*	44.99 %	40.03 %
Titania, TiO_2	trace	—	0.00 %	0.07 %
Phosphorus Pentoxide, P_2O_5	0.096%	0.045%	0.006%	0.012%
Manganous Oxide, MnO	0.13 %	0.135%	trace	trace
Total	100.216%	100.250%	100.276%	100.292%

TABLE II (Continued)

Quartz, SiO_2	7.94 %	0.000%	0.075%	6.34 %
Kaolinite, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	0.43 %	2.20 %	0.000%	4.63 %
Hematite, Fe_2O_3	0.06 %	trace	0.065%	0.26 %
Siderite, $FECO_3$	0.42 %	4.08 %	0.064%	0.71 %
Dolomite, $MgCO_3 \cdot CaCO_3$	2.88 %	17.43 %	26.803%	29.18 %
Calcite, $CaCO_3$	88.05 %	*76.35 %*	73.238%	59.09 %
Water (uncombined)	0.08 %	trace	0.05 %	0.13 %
Rutile, TiO_2	trace	0.00 %	0.00 %	0.07 %
Apatite, $CaF_2 \cdot 3Ca_3P_2O_8$	0.24 %	0.11 %	0.014%	0.03 %
Pyrolusite, MnO_2	0.16 %	0.17 %	trace	trace
Total	100.26 %	100.34 %	100.309%	100.44 %

Serial	Q	R 64	S	T 368
Silica, SiO_2	32.28 %	0.88 %	0.41 %	16.83 %
Alumina, Al_2O_3 (corrected)	4.88 %	0.00 %	0.167%	5.11 %
Ferric Oxide, Fe_2O_3	1.13 %	0.05 %	0.157%	3.23 %
Ferrous Oxide, FeO	—	0.08 %	—	trace
Magnesia, MgO	11.66 %	20.08 %	21.18 %	trace
Calcium Oxide, CaO	18.68 %	31.96 %	30.71 %	39.76 %
Sodium Oxide, Na_2O	0.15 %	—	0.029%	0.43 %
Potassium Oxide, K_2O	3.01 %	—	0.051%	0.79 %
Water (uncombined), H_2O	0.21 %	0.16 %	0.11 %	0.66 %
Water (combined, H_2O	*0.49 %	0.00 %	*0.02 %*	*1.26 %*
Carbon Dioxide, CO_2	*27.86 %*	*46.38 %*	*47.14 %*	*5.49 %*
Titania, TiO_2	—	0.00 %	—	0.35 %
Phosphorus Pentoxide, P_2O_5	—	0.59 %	0.004%	24.90 %
Fluorine, F	—	—	—	2.15 %
Sulfur Trioxide, SO_3	—	—	0.031%	trace
Manganous Oxide, MnO	—	trace	—	0.176%
Total	100.35 %	100.18 %	100.009%	101.136%
Less Oxygen equivalent to Fluorine,	0.90 %			100.236%
Quartz, SiO_2	18.28 %	0.88 %	0.00 %	7.13 %
Kaolinite, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	3.47 %	0.00 %	0.16 %	8.99 %
Albite, $NaAlSi_3O_8$	1.27 %	0.00 %	0.25 %	3.64 %
Orthoclase, $KAlSi_3O_8$	17.78 %	0.00 %	0.30 %	4.67 %
Hematite, Fe_2O_3	—	0.05 %	0.16 %	3.23 %
Siderite, $FeCO_3$	1.64 %	0.13 %	—	—
Dolomite, $MgCO_3 \cdot CaCO_3$	53.33 %	91.84 %	96.88 %	—
Calcite, $CaCO_3$	4.40 %	5.80 %	2.20 %	12.48 %
Apatite, $CaF_2 \cdot 3Ca_3P_2O_8$	—	1.40 %	0.01 %	58.95 %
Water (uncombined)	0.21 %	0.16 %	0.11 %	0.66 %
Rutile, TiO_2	—	—	—	0.35 %
Pyrolusite, MnO_2	—	—	—	0.22 %
Anhydrite, $CaSO_4$	—	—	0.05 %	—
Total	100.38 %	100.26 %	100.12 %	100.32 %

Literature

1. Blank, E. W. 1943. Reversible chromatic thermosensitivity. J. Chem. Ed. 20, 171.
2. Fansett, G. R. 1951. Field tests for the common metals. 10th ed. Bull. 157, Arizona Bur. Mines, Univ. of Ariz., Tucson, Ariz.
3. Fry, W. H. 1933. Petrographic methods for soil laboratories. U. S. Dept. Agr. Tech. Bull. 344.
4. Granderye, L. M. 1953. *Traite' pratique d'analyse par voie seche.* Dunod. Paris.
5. Ham, Wm. E. 1949. Okla. Geol. Surv., Circular 26, Citations, Q and S, Table 2.
6. Holmes, A. 1940. *Petrographic methods and calculations.* 3rd ed. Thos. Murby & Co. London.
7. Larsen, E. S. 1934. et al. The microscopic determination of the non-opaque minerals. 2nd ed. U. S. Geol. Surv. Bull. 848.
8. McCrone, W. C., Jr. 1952. Polarized light microscopy. Special Tech. Pub. 143 Amer. Soc. Testing Materials.
9. Milner, H. B. 1962. *Sedimentary petrography.* 4th ed. The Macmillan Co. New York.
10. Shead, A. C. 1929. Chemical analyses of Oklahoma mineral raw materials. Okla. Geol. Surv. Bull. 14. All serial numbers in Table 2 except Q and S.
11. Short, M. N. 1940. Microscopic determination of the ore minerals. 2nd ed. U. S. Geol. Surv. Bull. 914. Microchemical methods pp 173-292.
12. Smith, O. C. 1954. *Indentification and qualitative chemical analysis of minerals.* 2nd ed. D. Van Nostrand. New York.
13. Washington, H. S. 1917. Chemical analysis of igneous rocks. U. S. Geol. Surv. Prof. Paper H 99:1166-1180.
14. West, P. W. 1954. Polarized light microscopy. Chemist-Analyst 43:46, 56, 77, 109.
15. Wilson, C. L. 1938. *An introduction to microchemical methods.* Chem. Pub. Co. New York.

Note: All the above literature contains extensive bibliographies.

ACKNOWLEDGEMENTS

Financial assistance from the Oklahoma University Faculty Research Fund is hereby gratefully acknowledged.