G. R. OLHOEFT

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The relation of specific gravity to chemical composition for crystalline rocks

By

E. J. Young and G. R. Olhoeft

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Abstract

Equations and curves showing the relation of specific gravity to chemical composition have been developed for a suite of 58 Tertiary igneous rocks and 22 Precambrian rocks. Specific gravity was obtained with an air pycnometer and rock types are distinguished with a felsic-mafic index, $F = \frac{SiO_2 + \overset{Na_2O}{\cancel{H_2O}} + K_2O}{FeO + Fe_2O_3 + MgO + CaO}$

From specific gravity determinations on powder samples the equation for specific gravity, P, is $P = 2.643 + 0.444\, e^{-F/4}$; the standard deviation, σ, is $\pm$ 0.057. An equation developed from specific gravity data on bulk rock samples is not as good because of the adverse effect of occluded pore space; $\sigma = \pm 0.074$. The relation is most useful for rocks more dense than 2.67.

Introduction

One of the most fundamental properties of a rock is its specific gravity, yet in no rock classifications of either the past or present does it play a role. There are several reasons for its omission as a parameter in rock classification, one of the most serious being its variability for rocks having the same or nearly the same chemical composition. On closer inspection, however, this variability can often be traced to either dissimilar origins or metamorphism; specifically to the formation of either high or low density minerals. Another drawback has been the use of bulk rock specific gravity instead of grain or powder specific gravity. Bulk rock specific gravity determination is generally inaccurate because pore space and open fractures vary between samples of the same rock. Powder specific gravity determinations have usually been made using the pycnometer method which requires temperature standardization and painstaking technique. Hence it is no wonder that such determinations are not common.

Probably the most exhaustive work on the correlation of specific gravity and rock composition has been done by Kopf (1966), who also studied the physical properties of porosity, radioactivity, and magnetic susceptibility in their relation to rock composition. Saxov and Abrahamsen (1964), Kopf (1967), and Platou (1968) have lately grappled with the specific gravity--rock composition problem.

Use of the air pycnometer has made specific gravity determinations easy and relatively fast. Both powder and bulk rock specific gravities may be determined. McIntyre, Welday, and Baird (1965) discuss the use and precision of the air pycnometer, especially compared with that of the Jolly balance, and conclude that it can yield higher precision than that of the Jolly balance. Even more important, however, is the capability of the air pycnometer to determine powder specific gravity, which the Jolly balance cannot do.

Measurement of volume in the present study was usually repeated three times, and accuracy of measurement was maintained by frequent standardization using a steel sphere of known volume. Volumes of bulk samples averaged 18 cm^3, and of powder samples 15 cm^3. These volumes are routinely measured within ± 0.03 cm^3. Weights were measured on a micro-balance to the nearest milligram, or less. Resulting specific gravities are correct to ± 0.004 to ± 0.008 g/cm^3, which yield relative errors of about ± 0.2 percent.

The felsic-mafic index

Silica content is usually used as an indicator of rock composition. However, in diagrams illustrating the relation between specific gravity and rock composition the felsic-mafic index, $\frac{SiO_2 + Na_2O + K_2O}{FeO + Fe_2O_3 + MgO + CaO}$ yields a diagram with less scatter (better curve) because the felsic-mafic index quantifies the rock more comprehensively than SiO_2 alone. The felsic-mafic index was introduced by Segerstrom and Young (1972).

As a basis for classification, felsic-mafic indices were calculated from average chemical compositions of eight rock types ranging from alkali granite to gabbro listed by Nockolds (1954). Fine-grained rock equivalent names are shown in parentheses and follow the nomenclature of Streckeisen (1967). Table 1 lists the rock types, the number of Nockolds' samples contributing to the average chemical composition of each rock type, and the resulting felsic-mafic indices.

Presentation of data

Of the 80 rocks from Colorado used in this study, 58 are Tertiary igneous rocks, all but one of which are intrusive, and 22 are Precambrian metamorphic rocks. Chemical analyses of 11 of the Tertiary igneous rocks and 12 of the Precambrian metamorphic rocks have been published by

Segerstrom and Young (1972). Chemical analyses of the remainder of the Tertiary igneous rocks have been placed on open file by Young (1972). Table 2 lists 70 of the rocks, whose chemical analyses are published or open-filed, by field number and gives their names, references, felsic-mafic indices, powder and bulk rock specific gravities. Table 3 gives similar information plus unpublished chemical analyses for the 10 remaining metamorphic rocks.

Figure 1 shows the curve of the equation $P = 2.643 + 0.444e^{-\frac{F}{4}}$, where P = specific gravity and F = the felsic-mafic index, developed from the specific gravity data on powder samples (64 data points). The standard deviation, $\sigma = \pm 0.057$, is shown with a dashed line. To find the felsic-mafic index from the specific gravity the equation is: $F = -4 \ln \left(\frac{P - 2.643}{0.444}\right)$.

Figure 2 shows the corresponding curve and equation, $P = 2.619 + 0.497e^{-F/4}$, based on the bulk rock specific gravity data (78 data points). Because of the adverse effect of occluded pore space this curve is not as useful. Standard deviation is $\sigma = \pm 0.0739$, shown with a dashed line. On Figure 1 rock types are shown on the abscissa according to felsic-mafic indices developed from Table 1 and rock types on the ordinate from corresponding specific gravity data. It is apparent that specific gravity is of little use to distinguish rocks more felsic than quartz monzonite.

Table ~~1~~ 2.--~~Densities~~ Specific gravities and felsic-mafic indicies of 58 Tertiary igneous rocks and 12 Precambrian metamorphic rocks from Colorado.

Field No.	Name	References	F/M index	Powder ~~density~~ specific gravity	Bulk rock ~~density.~~ specific gravity
		Tertiary igneous rocks			
660[1/2]	Andesite	Segerstrom and Young (1973), and Young (1972)	2.67	2.862	2.855
661[2]	Basalt	---------do---------	2.10	2.775	2.743
662	Rhyolite porphyry	Young (1972	18.1	2.580	2.588
663	----do----------	---------do---------	18.2	2.568	2.568
663A	Quartz latite porphyry	---------do---------	10.0	2.633	2.615
664	Rhyolite porphyry	---------do---------	22.3	2.640	2.606
665	----do----------	---------do---------	19.6	2.667	2.622
666	----do----------	---------do---------	19.3	2.632	2.618
667	----do----------	---------do---------	15.8	2.488	2.497
668	----do----------	---------do---------	20.2	2.578	2.520
669	Quartz andesite porphyry	---------do---------	5.39	2.685	2.654
670	Rhyolite porphyry	---------do---------	18.9	2.653	2.637
671	Quartz andesite porphyry	Young (1972), and Segerstrom and Young (1973)	6.23	2.701	2.685
672	----do----------	---------do---------	5.94	2.711	2.693
673	Rhyolite porphyry	Young (1972)	16.4	2.651	2.637

Field No.	Name	References	F/M index	Powder density specific gravity	Bulk rock density- specific gravity
675	Quartz latite porphyry	Young (1972)	15.2	2.662	2.623
676	----do-----------	---------do--------	10.9	2.682	2.646
1C	Quartz andesite porphyry	Young (1972), and Segerstrom and Young (1973)	6.58	2.694	2.638
13B	Latite porphyry	---------do--------	4.65	2.795	----
33C	Extreme alkali rhyolite porphyry	Young (1972)	34.3	2.605	2.501
38C	Alkali rhyolite porphyry	---------do--------	32.3	2.622	2.511
41C	Alkali rhyolite porphyry	---------do--------	25.6	2.678	2.640
79[3]	Quartz andesite porphyry	---------do--------	6.88	2.874	2.890
80	----do-----------	---------do--------	5.48	2.801	2.790
132	Latite porphyry	Young (1972) and Segerstrom and Young (1973)	3.80	2.823	-----
159-67	Quartz andesite porphyry	Young (1972)	5.64	2.817	2.802
219	----do-----------	---------do--------	5.22	2.828	2.806
182	Rhyolite porphyry	Young (1972) and Segerstrom and Young (1973)	18.6	2.617	2.520

Field No.	Name	References	F/M index	Powder ~~density~~ Specific gravity	Bulk density Specific gravity
183	Alkali rhyolite porphyry	Young (1972) and Segerstrom and Young (1973)	25.8	2.649	2.630
221	Quartz latite porphyry	---------do--------	14.4	2.651	2.618
245	----do---------	---------do--------	12.0	2.671	2.620
247	----do---------	Young (1972)	12.3	2.669	2.655
297A	Rhyolite porphyry	---------do--------	16.2	2.662	2.628
1-71[4]	Monzonite porphyry	---------do--------	3.10	2.849	2.843
2-71[5]	Diorite	---------do--------	2.41	2.943	2.920
3-71[5]	Monzonite	---------do--------	3.22	2.753	2.655
4-71	Extreme alkali rhyolite	---------do--------	34.2	2.635	2.641
6-71	Granodiorite	---------do--------	7.02	2.724	2.694
7-71	Quartz diorite	---------do--------	5.45	2.733	2.720
8-71	----do---------	---------do--------	6.73	2.729	2.675
9-71	Granodiorite	---------do--------	7.18	2.718	2.698
10-71	----do---------	---------do--------	8.04	2.708	2.719
12-71	Quartz diorite	---------do--------	4.87	2.773	2.743
13-71	Quartz diorite porphyry	---------do--------	5.47	2.637	2.585
14-71	Monzonite	---------do--------	4.56	2.645	2.590

Field No.	Name	Reference	F/M index	Powder ~~density~~ specific gravity	Bulk rock density specific gravity
15-71	Mon~~az~~zonite	Young (1972)	3.50	2.842	2.811
16-71	----do-------	---------do---------	4.54	2.817	2.793
17-71	Extreme alkali rhyolite	---------do---------	75.1	2.634	2.626
18-71	Monzonite porphyry	---------do---------	3.58	2.755	2.707
19-71	Granodiorite porphyry	---------do---------	7.34	2.703	2.672
20-71	Quartz diorite	---------do---------	6.78	2.738	2.729
21-71	Granodiorite	---------do---------	7.47	2.715	2.696
22-71	Quartz monzonite	---------do---------	10.3	2.717	2.709
23-71	Granodiorite	---------do---------	7.02	2.719	2.694
24-71	Quartz monzonite	---------do---------	15.2	2.661	2.633
25-71	Granodiorite	---------do---------	7.55	2.710	2.710
26-71	Granodiorite	---------do---------	9.62		2.68+
27-71	Quartz monzonite	---------do---------	10.9		2.62+
		Precambrian metamorphic rocks			
110-67	Schist	Segerstrom and Young (1973)	11.0	2.772	2.782
1-68	----do---------	---------do---------	11.7	-----	2.716
3-67	Biotite gneiss	---------do---------	2.12	2.910	2.886
78-67	----do---------	---------do---------	5.56	2.815	2.827
52-68	Amphibolite	---------do---------	2.02	-----	2.971
124-68	----do---------	---------do---------	1.85	-----	3.026

Field No.	Name	Reference	F/M index	Powder ~~density~~ specific gravity	Bulk rock ~~density~~ specific gravity
227-67	Felsic gneiss	Segerstrom and Young (1973)	33.0	2.656	2.651
95-68	----do----------	---------do---------	40.8	------	2.641
21-68	Gneiss	---------do---------	16.0	------	2.668
129-68	----do----------	---------do---------	10.6	------	2.717
96-68	Quartz diorite gneiss	---------do---------	10.6	------	2.708
228-68	------do--------	---------do---------	9.73	------	2.697

[1] Extrusive rock.

[2] Contains modal olivine.

[3] Sample size (~3.4 cc)--too small for reliable ~~density~~ specific gravity.

[4] Contains normative olivine.

[5] Contains both normative olivine and nepheline.

[6] Determined by George Neuerburg.

Discussion and conclusions

The first coefficient in the equations of figures 1 and 2 agrees remarkably well with the theoretical value of 2.648 (the density of quartz) for large values of F (felsic-mafic index). The value for the limit as F goes to zero must lie between 3.345 (density of CaO) and 5.745 (density of FeO) which is in good agreement with the statistical finding of 3.087 to 3.144, albeit that is somewhat low. The fact that this latter value is low indicates that hydrated mineral species are present, which are unaccounted for in the F/M index.

In general, rocks more mafic than quartz monzonite are fairly well categorized by specific gravity, whereas rocks more felsic than quartz monzonite are not well categorized by specific gravity due to rapid flattening of the curve.

Many of the deviant points such as 661, 13, 14, 662, 663, 667, and 668 in figure 1 have lower than normal powder specific gravities because of the presence of hydrated minerals. If the water content of the rock is known a correction for specific gravity could be made which would place the point closer to the curve. Powder or grain specific gravity is preferable to bulk rock specific gravity in trying to relate specific gravity to rock composition.

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FIGURE 1

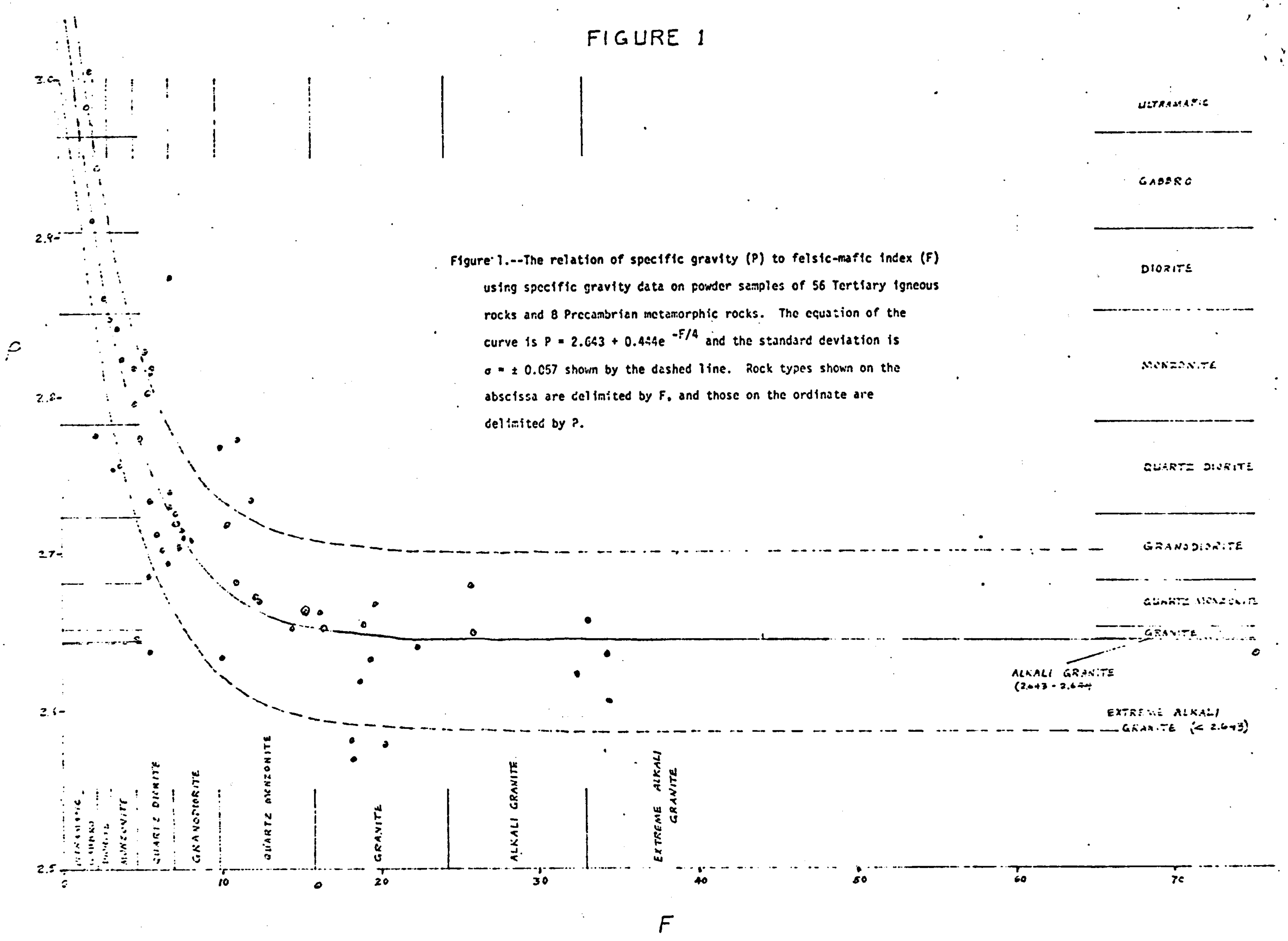

Figure 1.--The relation of specific gravity (P) to felsic-mafic index (F) using specific gravity data on powder samples of 56 Tertiary igneous rocks and 8 Precambrian metamorphic rocks. The equation of the curve is $P = 2.643 + 0.444e^{-F/4}$ and the standard deviation is $\sigma = \pm 0.057$ shown by the dashed line. Rock types shown on the abscissa are delimited by F, and those on the ordinate are delimited by P.

FIGURE 2

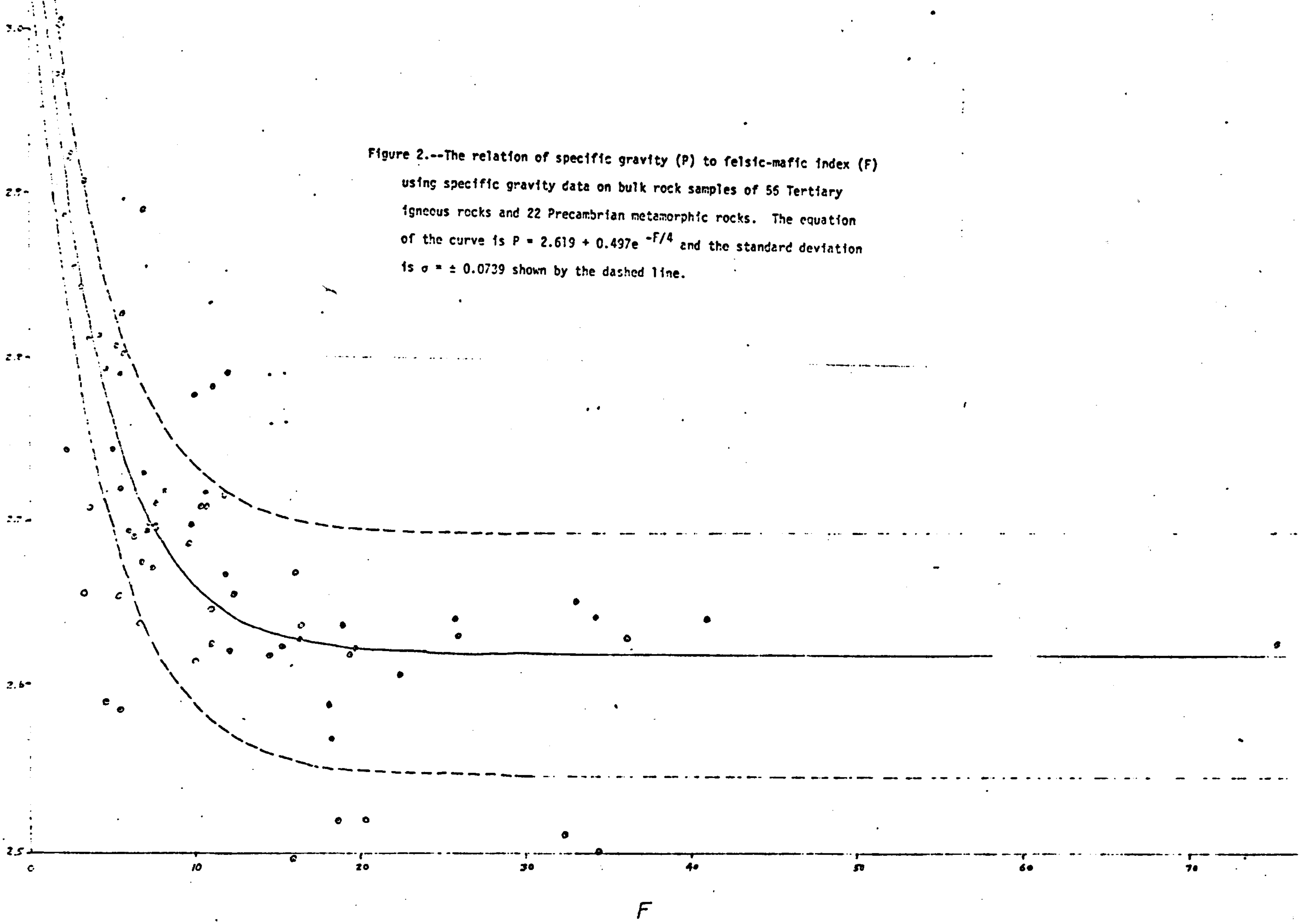

Figure 2.--The relation of specific gravity (P) to felsic-mafic index (F) using specific gravity data on bulk rock samples of 55 Tertiary igneous rocks and 22 Precambrian metamorphic rocks. The equation of the curve is $P = 2.619 + 0.497e^{-F/4}$ and the standard deviation is $\sigma = \pm 0.0739$ shown by the dashed line.