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THE FLOATABILITY OF ELEVEN NON-METALLIC MINERALS AND THREE METALLIC OXIDES (SEQUEL TO TB 108 AND TB 186)

R.A. WYMAN

Ore Processing Laboratory
Non-Metallic Section

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THE FLOATABILITY OF ELEVEN NON-METALLIC MINERALS AND THREE METALLIC OXIDES (SEQUEL TO TB 108 AND TB 186)

by

R.A. Wyman*

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ABSTRACT

The work is reported as part of a long-range study intended to fill a continuing demand for information on industrial mineral flotation. Previous work, already reported, covered about 21,000 trials. The present work covers about 10,000 additional trials.

The experimental procedure involves a simple, bubble pick-up method applied in acid, neutral and basic conditions under the influence of thirty-one different collectors and six common modifiers. The trade names and general chemical names for collectors and modifiers are listed in the report.

The method of assessing results includes comparison on a weighted average basis and a graphical form of presentation which conforms with earlier presentations. The present work includes data derived for actinolite, anhydrite, dolomite, gibbsite, hematite, lepidolite, magnetite, pollucite, pyrite, pyrophyllite, pyroxene, serpentine, sphene and wollastonite.

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Laboratoires des sciences minérales

RAPPORT DE CANMET 76-17

LA FLOTTABILITE DE ONZE MINERAUX NON-METALLIQUES ET DE TROIS OXYDES METALLIQUES (SUITE AU TB 108 ET TB 186)

par

R.A. Wyman*

RESUME

Le travail, ici rapporté, fait partie d'une étude à long terme initiée dans le but d'obtenir le plus de renseignements sur la flottation des minéraux industriels. Le travail précédent, dont on a déjà fait le rapport, s'était échelonné sur environ 21,000 essais, tandis que celui-ci s'intéresse à environ 10,000 essais supplémentaires.

Le procédé expérimental comprenait une simple méthode de barbotage appliquée dans des conditions acides, neutres ou basiques sous l'influence de trente-et-un collecteurs différents et de six modificateurs courants; leur marque de commerce et leur nom chimique sont donnés.

L'évaluation des résultats a été effectuée par comparaison sur une base de poids moyenne et une présentation graphique qui se conforme aux présentations antérieures. Le présent travail contient les données obtenues de l'actinolite, de l'anydrite, et la dolomie, de la gibbsite, de l'hématite, de la lépidolite, de la magnétite, de la pollucite, de la pyrite, de la pyrrophyllite, du pyroxène, de la serpentine, de la titanite et de la wollastonite.

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CONTENTS

INTRODUCTION

The information herein reported was gathered as part of the Minerals Research Program. It is the aim of this program to ensure the extraction and utilization of Canada's minerals and development. In the translation of non-metallic minerals from their natural state into useful materials, the techniques of flotation are frequently employed. The substance of this report, expanding similar information published earlier[1,2,3,4], supports the aim of the program by extending knowledge of a useful extraction technique.

At the same time it makes available to the public in general and to other processing laboratories and mineral producing operations in particular, information useful in resolving flotation problems. Canadian Patents No. 914,809 and 930,484, and United States Patent No. 3,710,934, have evolved from this research project, and earlier publications continue in demand. A number of useful processing systems have been developed based on facets of the work and it is expected that others will emerge.

BACKGROUND

For a number of years the Industrial Minerals Milling Section of the former Mineral Processing Division, Mines Branch, employed a small-scale test to aid in solving flotation problems. The method was simple and direct. It was intended to be indicative rather than definitive; a guide rather than a solution.

Because the information obtained had proven helpful in solving a number of problems, it was decided to publish the results. Technical Bulletin TB 70[1] was issued in 1965 and presented the results of approximately 4,000 of the small-scale experiments, designed to indicate the floatability of eleven non-metallic minerals under a variety of conditions. Its purpose was to point out possible new approaches for the separation of non-metallic minerals by flotation, particularly where separation was difficult, and to suggest possible methods of separating minerals for which no effective system was known.

By 1969, the work had been extended to cover approximately 14,000 of the small-scale experiments, showing flotation for 21 non-metallic minerals (the original 11, plus 10 more) in response to 31 collectors as well as the influence of 6 common modifiers. These results were reported in Technical Bulletin TB 108[2].

Because of continuing wide demand for information in this field, well over 7,000 additional experiments were reported in 1974 in Technical Bulletin TB 186[3]. The present work covers a further 10,500 experiments.

EXPERIMENTAL PROCEDURE

Minerals to be investigated are obtained in the purest form available, as crystals where possible. Each mineral is pulverized and the 28 to 325 mesh fraction is isolated. This fraction is selected because most non-metallic flotation is done within this size range and a rough visual estimation of the number of particles picked up by a bubble can be made.

These individual fractions are rinsed lightly with dilute HCl and then washed with distilled water to neutral pH. The intent is to clean the surfaces without etching or altering them significantly. Each mineral is stored in distilled water.

The apparatus consists of a small turntable, a beaker, a stirring rod, and a glass tube with a rubber eyedropper bulb and screw clamp at its top. Before starting an experiment, the beaker, stirring rod and glass tube are rinsed with chromic-acid cleaning solution and washed thoroughly with distilled water. Measuring devices such as graduates and pipettes are similarly cleaned once or twice a day.

A single experiment consists of the following steps:

(1) About 100 ml of distilled water is put into the beaker.

(2) About 0.01 g of the particular mineral to be examined is added.

(3) The pH regulator, when used, is added and mixed by stirring rod.

(4) Modifier to give 0.05 g/l concentration, when used, is added and mixed by stirring rod.

(5) Collector to give 0.1 g/l concentration is added and mixed by stirring rod.

(6) The beaker is placed on the turntable. The tube with eye-dropper is lowered vertically until its open end is about one-half inch above the mineral.

(7) The screw clamp on the rubber bulb is turned to produce a bubble at the lower end of the glass tube.

(8) The beaker and turntable are raised until the bubble makes contact with the mineral.

(9) The beaker is lowered until the bubble and adhering particles are surrounded by the liquid.

(10) Number of particles adhering to the bubble are estimated (0, 1, 2, 10, 15, etc.).

(11) The glass tube is lightly tapped and the tenacity with which the particles cling to the bubble is estimated (i.e., poor, fair, or good).

(12) Estimations are recorded on a standard form.

The experiments progress from simple to more complex. The first step is to run a blank, i.e., the bubble is placed in contact with the mineral in distilled water only. With many minerals, several particles will be picked up but drop off as soom as the tube is tapped lightly. Each mineral is then tested for response to each collector in turn, under acidic, neutral and basic conditions. In the neutral case, the system consists only of the mineral and the collector in distilled water. For acidic conditions, 1 ml of H_2SO_4 of a predetermined concentration is added from a 1-ml dispensing bottle. The acid is of such a concentration that when 1 ml is added to 100 ml of distilled water, a pH of 3.0 will result. Similarly, for basic conditions, 1 ml of Na_2CO_3 of predetermined concentration is added from a 1-ml dispensing bottle, producing a pH of 10.0 in 100 ml of distilled water. For both the acidic and basic experiments, the regulator is mixed in by stirring and the collector is added and also mixed in by stirring before bubble contact is made.

The pH will vary slightly during the experiments owing to the presence of the mineral and the other reagents. However, the quantity of both mineral and reagents is comparatively small and the operations are conducted rapidly. It has been found that the pH varies little from that of the acid or base in distilled water. The maximum change in pH is observed when ionizing modifiers are used. Since the general acidic or basic nature of the system is not altered however, and the total variation is rarely beyond one pH point, it is considered preferable not to readjust the pH to the specified points. This would add greatly to the time required to perform an individual acidic or basic experiment. Moreover, since the observations are not absolute, the overall results must be considered as relative only. The one operation with any significant bias is that for "neutral" when HF is used as a modifier. The pH in this case is always slightly on the acid side. However, this would also be the case in larger-scale flotation practice.

In experiments with modifiers, each system - mineral, collector, and pH control - is repeated with each modifier. The modifier is added before the collector and mixed by stirring.

MINERALS INVESTIGATED

The criteria for selecting minerals for this study were that they come from natural occurrences and be nearly pure. Minerals reported upon are as follows:

	Mineral	Colour	Origin
1.	Actinolite	gray to brownish	Ontario
2.	Anhydrite	white	Nova Scotia
3.	Dolomite	white	Ontario
4.	Gibbsite	buff	Guyana
5.	Hematite	red	Brazil
6.	Lepidolite	purple	Manitoba
7.	Magnetite	black	Quebec
8.	Pollucite	white	Manitoba
9.	Pyrite	brass	British Columbia
10.	Pyrophyllite	cream	Newfoundland
11.	Pyroxene	green	Quebec
12.	Serpentine	light green	Quebec
13.	Sphene	dark brown	Ontario
14.	Wollastonite	white	New York

COLLECTORS INVESTIGATED

The principle of collection in flotation is simple - to render hydrophobic the surfaces of the mineral to be floated, thus allowing attachment to an air bubble and elevation to the surface. In theory this should be possible with any mineral. In practice there are many complicating factors, and finding a chemical that will be selective for one specific mineral in a mixture of minerals is by no means easy.

Since the mineral surface is the site of the action, the chemicals involved are the so-called surface-active agents (or surfactants). Broadly, these agents fall into three classes according to their activity - non-ionic, anionic, and cationic. Non-ionic agents do not ionize in solution. When anionic agents are dissolved, the negative ions or anions are active, and when cationic agents are dissolved, the positive ions or cations are active. Although fatty acids are anionic, they are widely used in non-metallic mineral flotation and, for the purpose of this report, have been considered as a fourth class.

There are many thousands of surfactants available and the list is continually increasing and changing. The older, stable types are rapidly being replaced by those that are biodegradable. For the purpose of flotation, these can be narrowed into a comparatively small number of general types with an even narrower grouping applicable to non-metallics. Reagents that are in more or less common use as flotation collectors have been included as well as newcomers.

The collectors used are listed below according to their class, trade name, and general chemical name.

NON-IONIC, Ethanol

Igepal CTA	Alkyl phenoxypoly-(ethyleneoxy)ethanol
Rexol 25J	Nonyl phenol polyethoxy ethanol

ANIONIC, Petroleum sulphonate

Reagent 801	"Green acid"-type petroleum sulphonate
Petroflote 462	Sodium alkyl-aryl petroleum sulphonic acid
Leonal SA	Naphthalene sulphonic acid derivative

ANIONIC, Fatty acid sulphonates

Emcol 4150	Fatty acid aliphatic sulphonate
Sulphonated castor oil	Sulphonated castor oil (60% fats)
Prestabit oil V	Sulphonated fatty acids

ANIONIC, Alkyl sulphate

Duponol 80	Sodium octyl sulphate
Nutrapon WAC	Sodium lauryl sulphate
Duponol OS	Diethyl cyclohexylamine lauryl sulphate

ANIONIC, Sodium taurate

Igepon TE 42	Sodium-N-methyl-N-tallow acid taurate
Igepon T 33	Sodium-N-methyl-N-oleoyl taurate
Igepon TN 74	Sodium-N-methyl-N-palmitoyl taurate

CATIONIC, Primary amine

Adogen 170A	Technical tallow amine acetate
Armac C	Coco amine acetate
Armeen L-9	Primary beta amine

CATIONIC, Diamine

Duomac T	Tallow diamine di-acetate
Duomac C	Coco diamine di-acetate
Duomeen L-11	Beta diamine

CATIONIC, Tertiary amine

Nalcamine G 11		Hydroxyethyl alkyl imidazoline (glyoxalidine)
Armeen	12 D	Lauryl amine
Armeen	DLM 11	Beta tertiary armine

CATIONIC, Quaternary ammonium compounds

Emcol E 607-40		N (lauroyl-colamino-formyl-methyl) pyridinium chloride
ARQUAD	12	n-alkyl trimethyl ammonium chloride
Retarder	LA	Cetyl trimethyl ammonium bromide
Ammonyx	T	Cetyl trimethyl benzyl ammonium chloride

FATTY ACID, Tall oil

Neofat 42-12	Tall oil base fatty acid
Actinol FA 2	Tall oil fatty acid

FATTY ACID, Oleic

Harfat 231	Oleic acid blend
Distilled oleic acid	Oleic acid

MODIFIERS INVESTIGATED

As pointed out in the previous section, flotation is effected by the action of a collector, causing the surface of a mineral to become hydrophobic. In many cases, however, it is necessary to also use modifying agents to achieve this. Such agents simply aid in getting the collector onto the surface of the mineral to be floated. This action is called activation. On the other hand, a modifying agent may prevent a collector from getting onto the surface of unwanted minerals. This action is called depression. These are probably the most important functions of modifiers.

The regulation of pH is itself a form of modifying: as indicated earlier, all the experiments were done at three pH levels. The cleaning of surfaces, dispersion of ultra-fine solids, precipitation of dissolved salts and other functions are handled by modifying agents. Some agents serve more than one purpose - e.g., sodium carbonate may act as a dispersant, activator, depressant, or means of pH control. Metal ions are believed to alter the mineral surfaces by being adsorbed on these surfaces. Organic colloids are thought to blank off surfaces. Organic acids may aid in activation, depression or cleaning surfaces.

The pH-controlling agents employed have been described under EXPERIMENTAL PROCEDURE. Other modifiers used in the experiments are: (1) three to provide ion resurfacing - $FeSO_4$ for iron, $Al_2(SO_4)_3$ for aluminum, and HF for fluorine; (2) two organic colloids to blank mineral surfaces - starch and dextrin; and (3) one organic acid - citric acid.

RESULTS

The object in the method of presenting the results is usability. Ready comparison of the results for individual minerals is necessary to facilitate selection of the liquid systems in which separations would be likely to take place. In this report, the estimations for each mineral have been condensed so that they will fit onto the front and back of a single sheet. Each sheet may be removed from the report so that it may be laid beside another or so that two or more may be overlapped for easier comparison.

Flotation is estimated for each mineral, according to collectors on the front of a page and according to modifiers on the back of a page. To make comparison as easy as possible, the floatability is depicted by four symbols - black for excellent, cross-hatched for good, stippled for fair, and blank for poor. Thus the darker areas, black and cross-hatched, generally indicate acceptable flotation, whereas the lighter areas, stippled and white, indicate unsatisfactory flotation at best.

In the initial recording of observations as described under EXPERIMENTAL PROCEDURE, the number of particles adhering to the bubble and the strength of the bond were indicated. Thus, 15G stood for about 15 particles picked up and firmly held by the bubble (good bond). If the record were 15F, then some or most of the particles could be dislodged by a light tapping on the bubble tube (fair bond). A record such as 3P would indicate that 3 particles were picked up and either dropped from the bubble after a moment or two or dropped after a light tap in the bubble tube (poor bond).

In assessing the results for this method of presentation, a form of weighted average must be used. This consists of arbitrarily allotting the number 1 to poor bond, 2 to fair bond and 3 to good bond, then multiplying the number of particles by these numbers. The aggregate of all cases divided by the number of cases is then used to determine the average floatability. An average below 10 is considered poor, between 10 and 25 fair, 25 to 40 good, and above 40 excellent. In the occasional doubtful case between poor and fair, or between fair and good, floatability has been indicated by using both symbols. Results which differ greatly from the average have not been used in the calculation, but are pointed out as exceptions.

Results are presented for the various minerals in alphabetical order, and each sheet is dated.

RESPONSE TO COLLECTORS **ACTINOLITE**

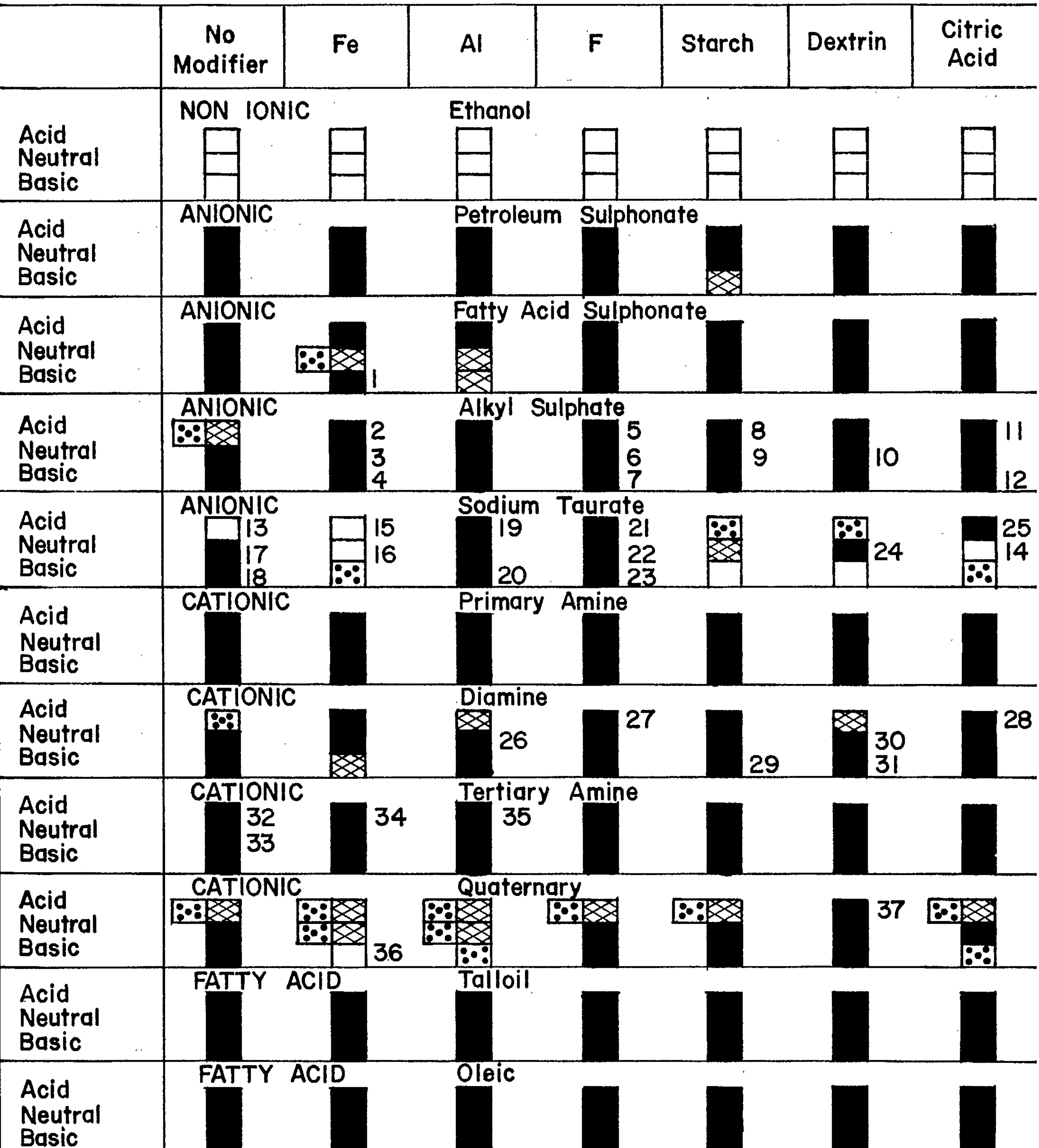
KEY: Excellent Flotation ■ Fair Flotation ⁘ Good Flotation ▩ Poor Flotation □

CLASS	No. Tested	Acid	Neutral	Basic
Non-ionic	2	Poor	Poor	Poor
Anionic	12	Good	Excellent	Excellent
Cationic	13	Good	Excellent	Excellent
Fatty acid	4	Excellent	Excellent	Excellent

Class	TYPE	No. Tested	Acid	Neutral	Basic
Non-ionic	Ethanol	2	Poor	Poor	Poor
Anionic	Petroleum sulphonate	3	Excellent	Excellent	Excellent
"	Fatty acid sulphonate	3	Excellent	Excellent	Excellent
"	Alkyl sulphate	3	Fair/Good	Excellent	Excellent
"	Sodium taurate	3	Poor	Excellent	Excellent
Cationic	Primary amine	3	Excellent	Excellent	Excellent
"	Diamine	3	Fair	Excellent	Excellent
"	Tertiary amine	3	Excellent	Excellent	Excellent
"	Quaternary	4	Fair/Good	Excellent	Excellent
Fatty acid	Talloil	2	Excellent	Excellent	Excellent
"	Oleic	2	Excellent	Excellent	Excellent

Date: June 1976

ACTINOLITE EFFECT OF MODIFIERS



1. Poor float with Emcol 4150
2 to 12. Poor float with Duponol OS
13,14. Excellent float with Igepon TE 42
15,16. Excellent float with Igepon T 33
17 to 25. Poor float with Igepon TN 74
26. Poor float with Duomac C
27,28. Poor float with Duomac T
29,30,31. Poor float with Duomeen L 11
32 to 35. Poor float with Nalcamine G 11
36. Excellent float with ARQUAD 12
37. Poor float with Retarder LA

Date: June 1976

RESPONSE TO COLLECTORS ANHYDRITE

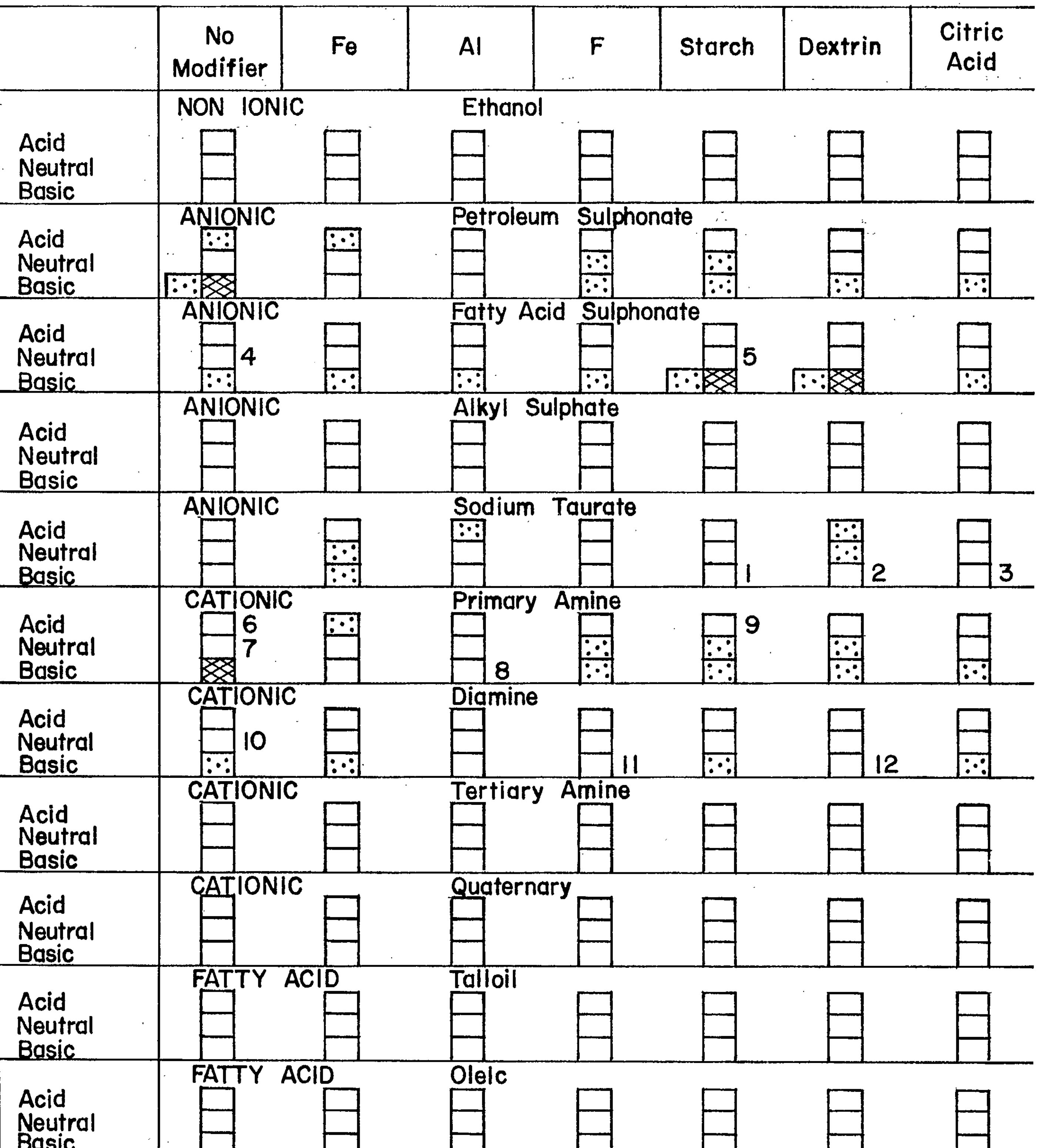
KEY: Excellent Flotation ■ Fair Flotation ⊡
Good Flotation ▩ Poor Flotation □

CLASS	No. Tested	Acid	Neutral	Basic
Non-ionic	2	Poor	Poor	Poor
Anionic	12	Poor	Poor	Poor / Fair
Cationic	13	Poor	Poor	Poor / Fair
Fatty acid	4	Poor	Poor	Poor

Class	TYPE	No. Tested	Acid	Neutral	Basic
Non-ionic	Ethanol	2	Poor	Poor	Poor
Anionic	Petroleum sulphonate	3	Fair	Poor	Fair / Good
"	Fatty acid sulphonate	3	Poor	Poor	Fair
"	Alkyl sulphate	3	Poor	Poor	Poor
"	Sodium taurate	3	Poor	Poor	Poor
Cationic	Primary amine	3	Poor	Poor	Good
"	Diamine	3	Poor	Poor	Fair
"	Tertiary amine	3	Poor	Poor	Poor
"	Quaternary	4	Poor	Poor	Poor
Fatty acid	Talloil	2	Poor	Poor	Poor
	Oleic	2	Poor	Poor	Poor

Date: June 1976

ANHYDRITE — EFFECT OF MODIFIERS



1. Excellent float with Igepon TE 42
2. Excellent float with Igepon TE 42
3. Excellent float with Igepon TE 42
4. Excellent float with Emcol 4150
5. Excellent float with Emcol 4150
6. Excellent float with Armac C
7. Excellent float with Armac C
8. Excellent float with Adogen 170A
9. Excellent float with Armac C
10. Excellent with Duomac C
11. Excellent with Duomac C
12. Excellent with Duomac T

Date: June 1976

RESPONSE TO COLLECTORS — DOLOMITE

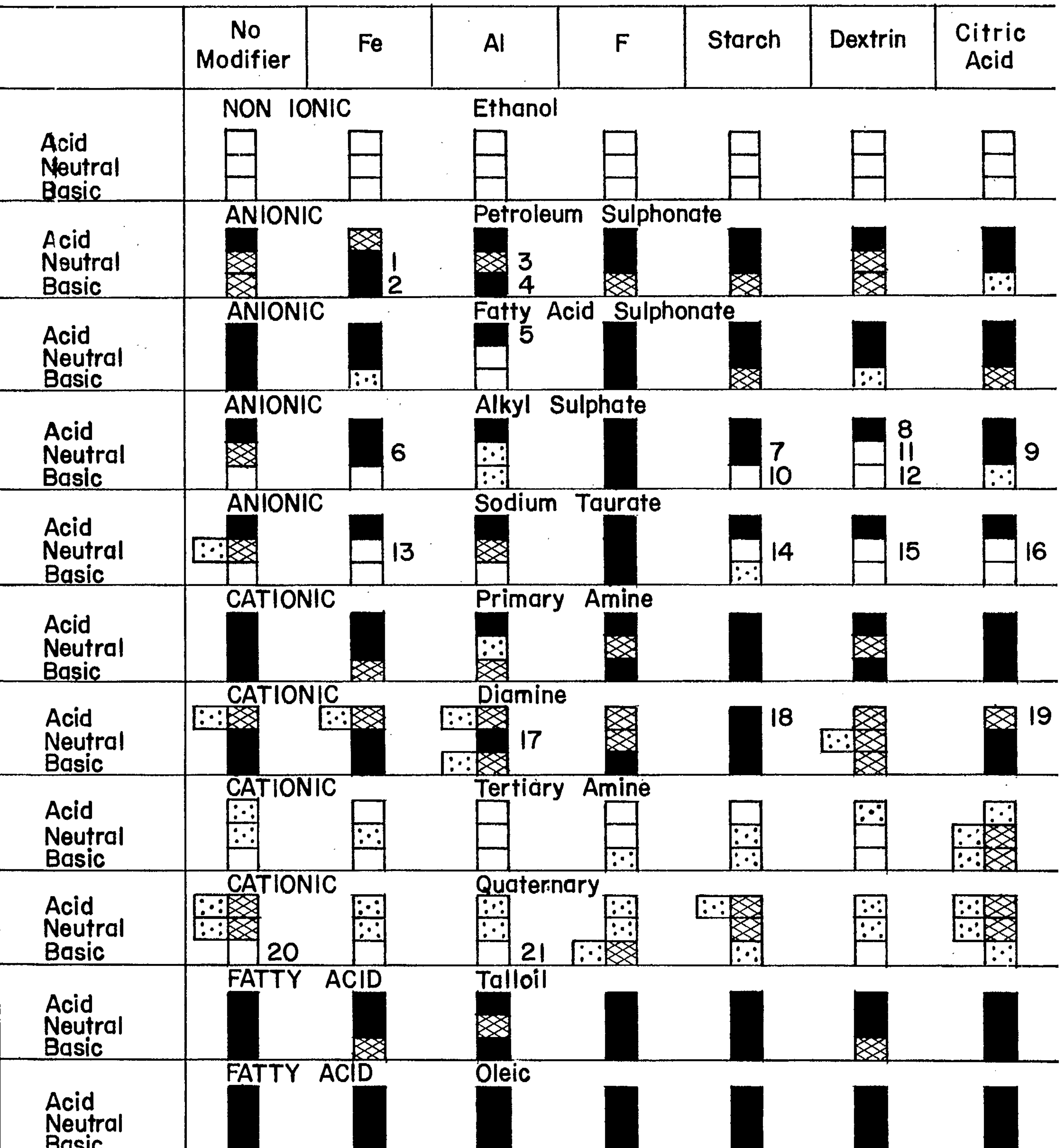
KEY: Excellent Flotation ■ — Good Flotation ▩ — Fair Flotation ⁛ — Poor Flotation □

CLASS	No. Tested	Acid	Neutral	Basic
Non-ionic	2	Poor	Poor	Poor
Anionic	12	Excellent	Good	Fair/Good
Cationic	13	Fair/Good	Good	Fair/Good
Fatty acid	4	Excellent	Excellent	Excellent

Class	TYPE	No. Tested	Acid	Neutral	Basic
Non-ionic	Ethanol	2	Poor	Poor	Poor
Anionic	Petroleum sulphonate	3	Excellent	Good	Good
"	Fatty acid sulphonate	3	Excellent	Excellent	Excellent
"	Alkyl sulphate	3	Excellent	Good	Fair
"	Sodium taurate	3	Excellent	Fair/Good	Poor
Cationic	Primary amine	3	Excellent	Excellent	Excellent
"	Diamine	3	Fair/Good	Excellent	Excellent
"	Tertiary amine	3	Fair	Fair	Poor
"	Quaternary	4	Fair/Good	Fair/Good	Poor
Fatty acid	Talloil	2	Excellent	Excellent	Excellent
"	Oleic	2	Excellent	Excellent	Excellent

Date: June 1976

DOLOMITE EFFECT OF MODIFIERS



1,2,3,4.	Poor float with Leonal SA
5.	Poor float with Emcol 4150
6,7,8,9.	Poor float with Duponol OS
10,11,12.	Excellent float with Duponol 80
13,14,15,16.	Excellent float with Igepon TE 42
17.	Poor float with Duomeen L-11
18,19.	Poor float with Duomac T
20,21.	Excellent float with ARQUAD 12

Date: June 1976

RESPONSE TO COLLECTORS GIBBSITE

KEY: Excellent Flotation ■ Fair Flotation ⊡

Good Flotation ▩ Poor Flotation □

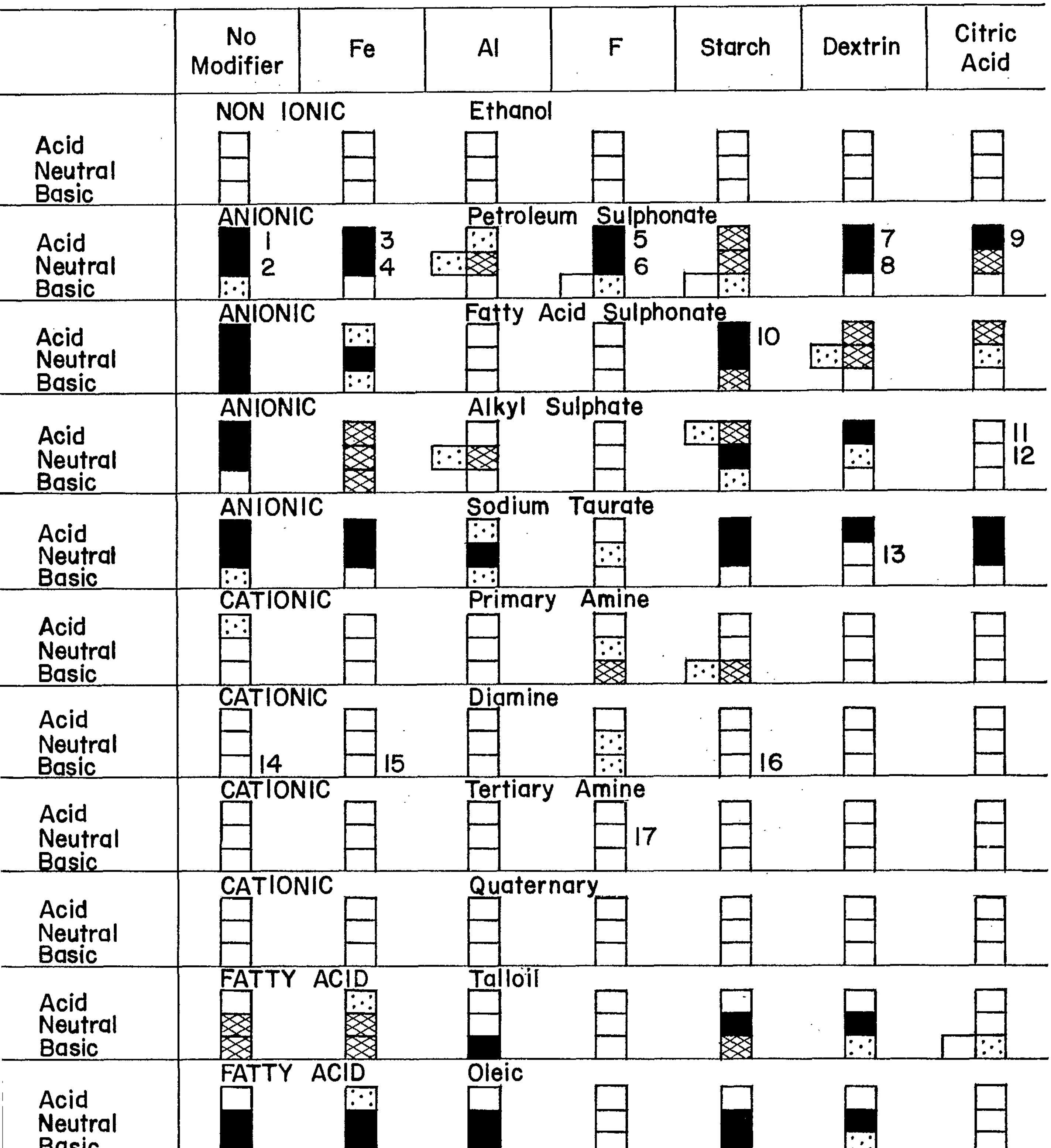
CLASS	No. Tested	Acid	Neutral	Basic
Non-ionic	2	□	□	□
Anionic	12	■	■	⊡
Cationic	13	□	□	□
Fatty acid	4	□	■	■

Class	TYPE	No. Tested	Acid	Neutral	Basic
Non-ionic	Ethanol	2	□	□	□
Anionic	Petroleum sulphonate	3	■	■	⊡
"	Fatty acid sulphonate	3	■	■	■
"	Alkyl sulphate	3	■	■	□
"	Sodium taurate	3	■	■	⊡
Cationic	Primary amine	3	□	□	□
"	Diamine	3	□	□	□
"	Tertiary amine	3	□	□	□
"	Quaternary	4	□	□	□
Fatty acid	Talloil	2	□	▩	▩
"	Oleic	2	□	■	■

Date: June 1976

GIBBSITE

EFFECT OF MODIFIERS



1 to 9. Poor float with Leonal SA
10. Poor float with Emcol 4150
11,12. Excellent float with Nutrapon WAC
13. Excellent float with Igepon TE 42
14,15,16. Excellent float with Duomac T
17. Excellent float with Armeen 12 D

Date: June 1976

RESPONSE TO COLLECTORS HEMATITE

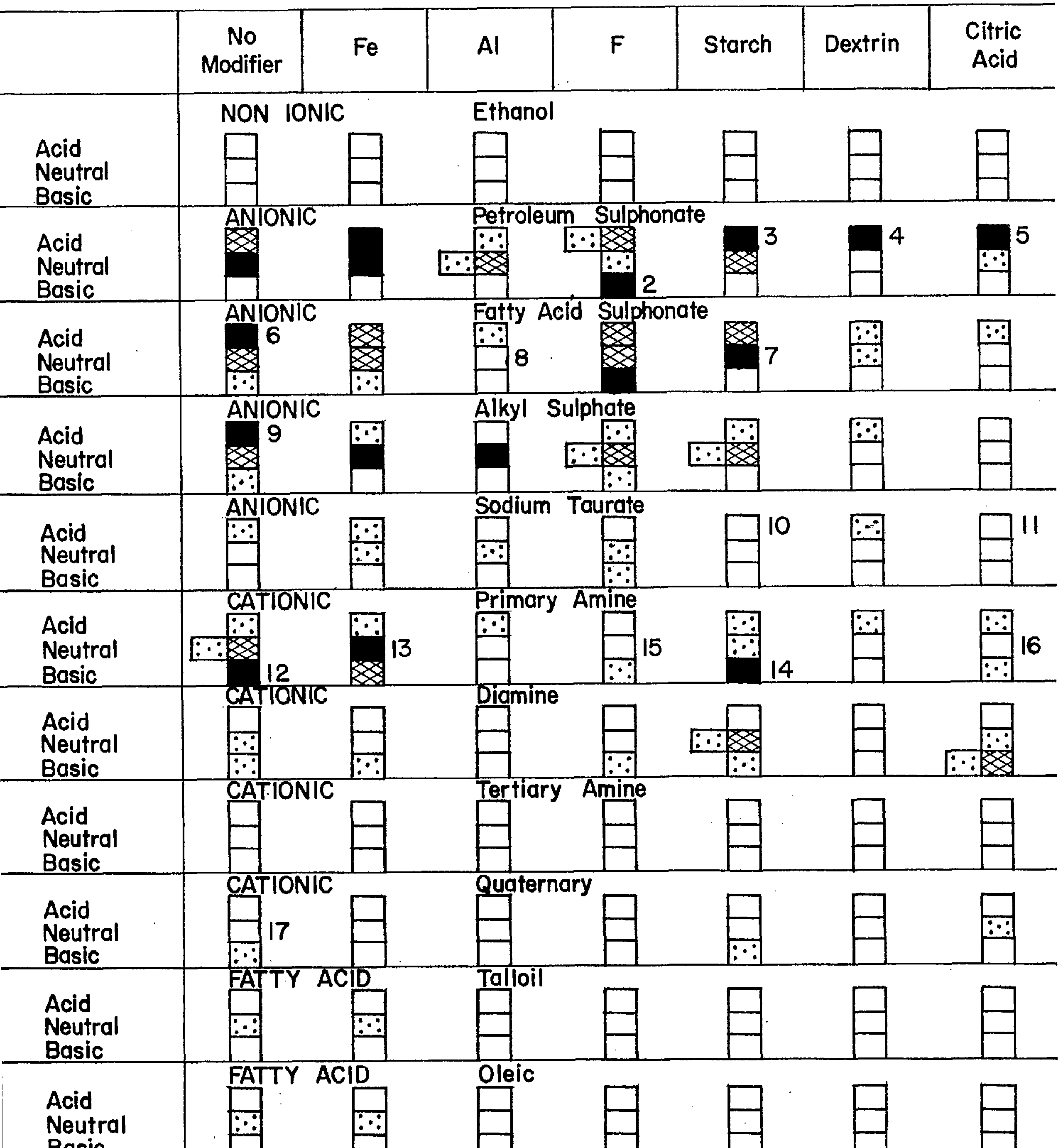
KEY: Excellent Flotation ■ Good Flotation ⊠ Fair Flotation ⁙ Poor Flotation □

CLASS	No. Tested	Acid	Neutral	Basic
Non-ionic	2	Poor	Poor	Poor
Anionic	12	Good	Good	Poor
Cationic	13	Poor	Fair	Fair
Fatty acid	4	Poor	Fair	Poor

Class	TYPE	No. Tested	Acid	Neutral	Basic
Non-ionic	Ethanol	2	Poor	Poor	Poor
Anionic	Petroleum sulphonate	3	Good	Excellent	Poor
"	Fatty acid sulphonate	3	Excellent	Good	Fair
"	Alkyl sulphate	3	Excellent	Good	Fair
"	Sodium taurate	3	Fair	Poor	Poor
Cationic	Primary amine	3	Fair	Fair/Good	Excellent
"	Diamine	3	Poor	Fair	Fair
"	Tertiary amine	3	Poor	Poor	Poor
"	Quaternary	4	Poor	Poor	Fair
Fatty acid	Talloil	2	Poor	Fair	Poor
	Oleic	2	Poor	Fair	Poor

Date: June 1976

HEMATITE EFFECT OF MODIFIERS



1,2,3,4,5. Poor float with Leonal SA
6,7. Poor float with Emcol 4150
8. Excellent float with Sulphonated Castor Oil
9. Poor float with Duponol 80
10,11. Excellent float with Igepon TE 42
12,13,14. Poor float with Armeen L-9
15,16. Excellent float with Adogen 170A
17. Excellent float with Emcol E 607-40

Date: June 1976

RESPONSE TO COLLECTORS LEPIDOLITE

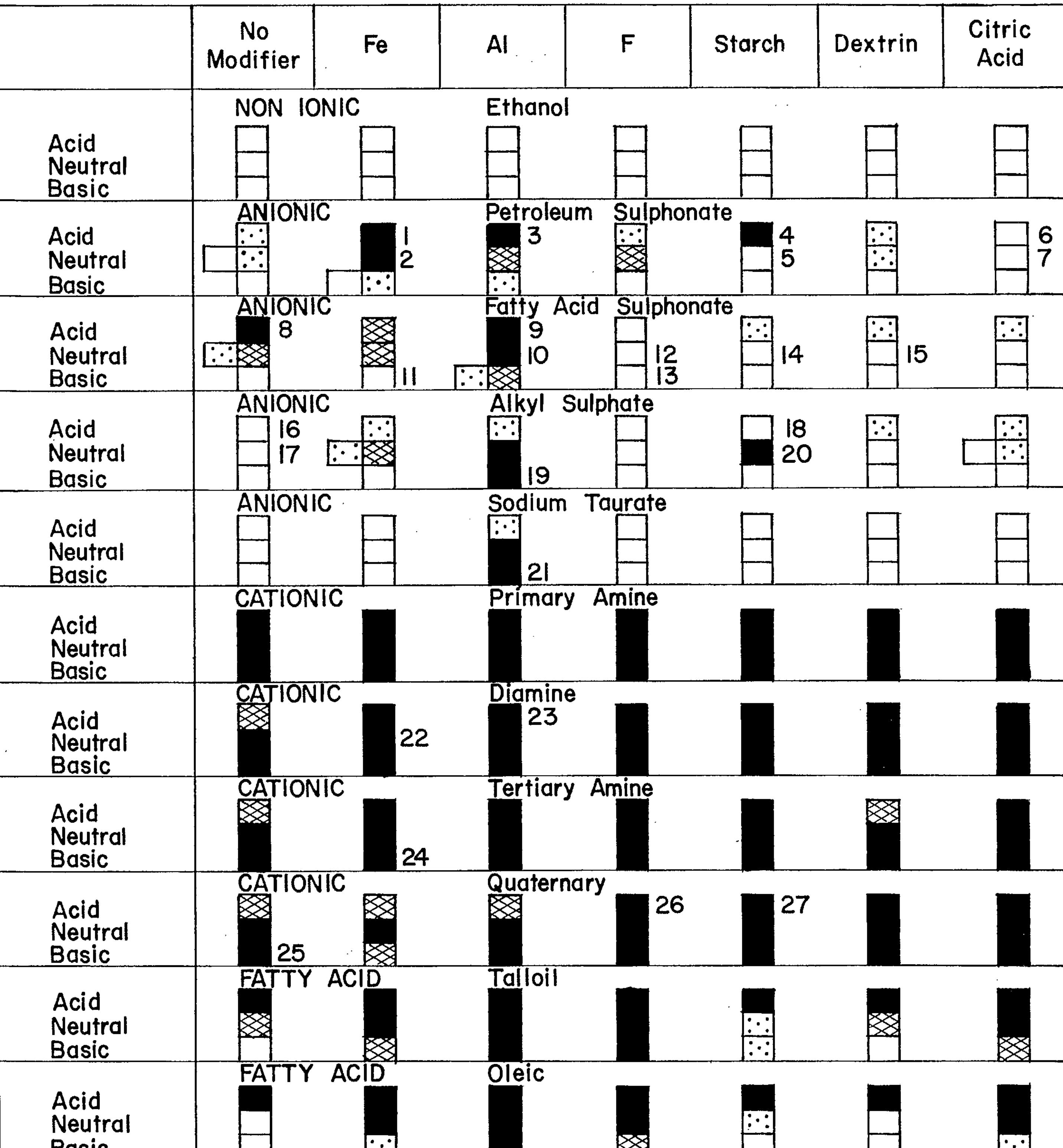
KEY: Excellent Flotation ■ Fair Flotation ⁙
Good Flotation ▩ Poor Flotation □

CLASS	No. Tested	Acid	Neutral	Basic
Non-ionic	2	□	□	□
Anionic	12	□⁙	□	□
Cationic	13	▩	■	■
Fatty acid	4	■	⁙	□

Class	TYPE	No. Tested	Acid	Neutral	Basic
Non-ionic	Ethanol	2	□	□	□
Anionic	Petroleum sulphonate	3	⁙	□⁙	□
"	Fatty acid sulphonate	3	■	⁙▩	□
"	Alkyl sulphate	3	□	□	□
"	Sodium taurate	3	□	□	□
Cationic	Primary amine	3	■	■	■
"	Diamine	3	▩	■	■
"	Tertiary amine	3	▩	■	■
"	Quaternary	4	▩	■	■
Fatty acid	Talloil	2	■	▩	□
"	Oleic	2	■	□	□

Date: June 1976

LEPIDOLITE EFFECT OF MODIFIERS



1 to 4. Poor float with Leonal SA
5. Excellent float with Petroflote 462
6,7. Excellent float with Reagent 801
11 to 15 Excellent float with Sulphonated Castor Oil
8,9,10. Poor float with Emcol 4150
16,17,18. Excellent float with Duponol 80
19,20. Poor float with Duponol OS
21. Poor float with Igepon TE 42
22,23. Poor float with Duomac T
24. Poor float with Nalcamine G 11
25. Poor float with Emcol E 607-40
26. Poor float with Ammonyx T
27. Poor float with Retarder LA

Date: June 1976

RESPONSE TO COLLECTORS — MAGNETITE

KEY: Excellent Flotation (solid box) · Good Flotation (cross-hatched box) · Fair Flotation (dotted box) · Poor Flotation (empty box)

CLASS	No. Tested	Acid	Neutral	Basic
Non-ionic	2	Poor	Poor	Poor
Anionic	12	Poor	Poor	Poor
Cationic	13	Poor	Poor	Poor
Fatty acid	4	Poor	Poor	Poor

Class	TYPE	No. Tested	Acid	Neutral	Basic
Non-ionic	Ethanol	2	Poor	Poor	Poor
Anionic	Petroleum sulphonate	3	Poor	Poor	Poor
"	Fatty acid sulphonate	3	Poor	Poor	Poor
"	Alkyl sulphate	3	Poor	Poor	Poor
"	Sodium taurate	3	Poor	Poor	Poor
Cationic	Primary amine	3	Poor	Fair	Fair
"	Diamine	3	Poor	Poor	Poor
"	Tertiary amine	3	Poor	Poor	Poor
"	Quaternary	4	Poor	Poor	Poor
Fatty acid	Talloil	2	Poor	Poor	Poor
"	Oleic	2	Poor	Poor	Poor

Date: June 1976

MAGNETITE

EFFECT OF MODIFIERS

		No Modifier	Fe	Al	F	Starch	Dextrin	Citric Acid
NON IONIC Ethanol	Acid							
	Neutral							
	Basic							
ANIONIC Petroleum Sulphonate	Acid							
	Neutral							
	Basic							
ANIONIC Fatty Acid Sulphonate	Acid							
	Neutral							
	Basic							
ANIONIC Alkyl Sulphate	Acid							
	Neutral							
	Basic							
ANIONIC Sodium Taurate	Acid							
	Neutral							
	Basic							
CATIONIC Primary Amine	Acid							
	Neutral	[stippled]						
	Basic	[stippled]	[stippled]			[stippled]		
CATIONIC Diamine	Acid							
	Neutral							
	Basic							
CATIONIC Tertiary Amine	Acid							
	Neutral							
	Basic							
CATIONIC Quaternary	Acid							
	Neutral							
	Basic							
FATTY ACID Talloil	Acid							
	Neutral							
	Basic							
FATTY ACID Oleic	Acid							
	Neutral							
	Basic							

Date: June 1976

RESPONSE TO COLLECTORS POLLUCITE

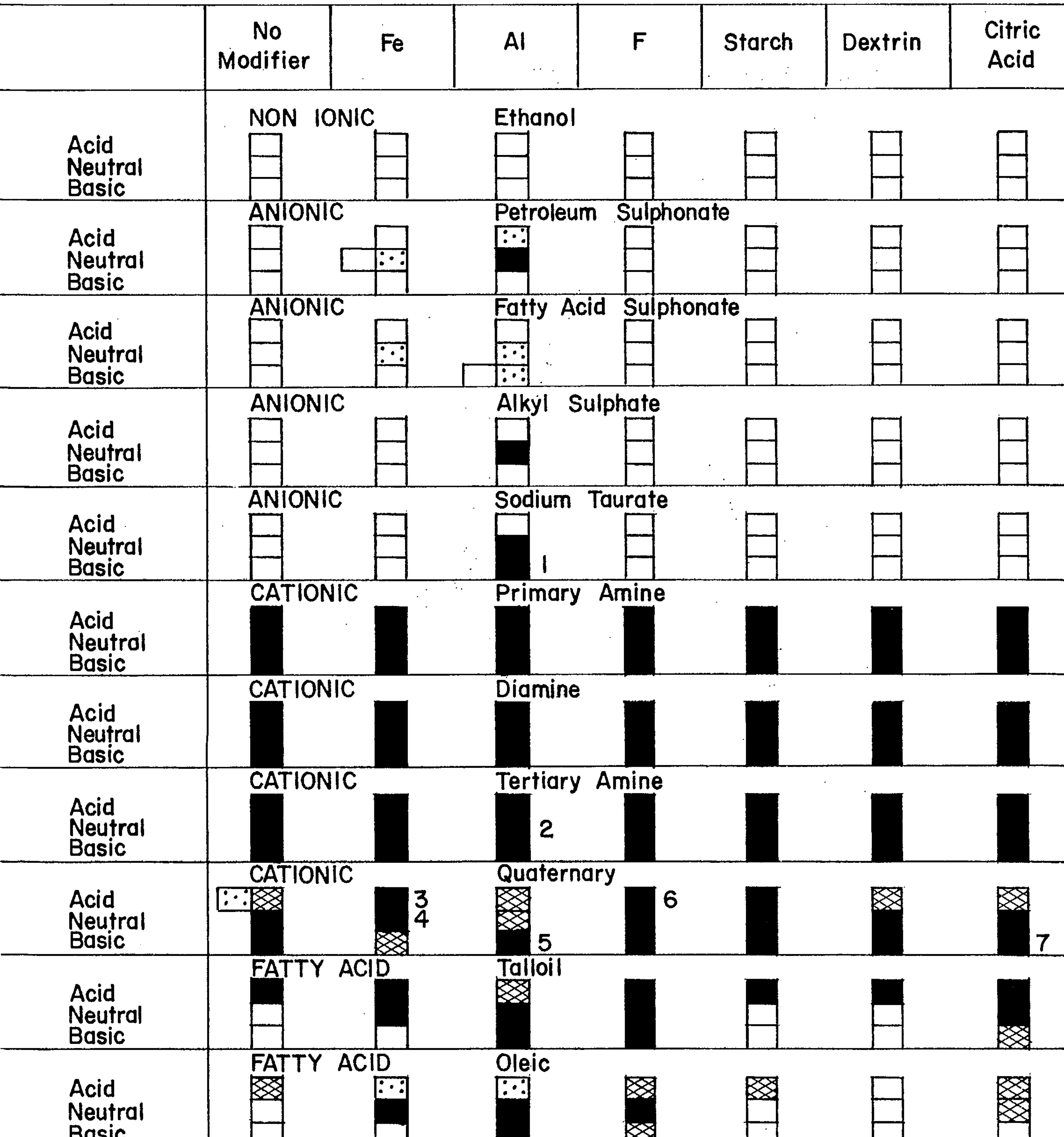
KEY: Excellent Flotation ■ Fair Flotation ⁙ Good Flotation ▩ Poor Flotation □

CLASS	No. Tested	Acid	Neutral	Basic
Non-ionic	2	Poor	Poor	Poor
Anionic	12	Poor	Poor	Poor
Cationic	13	Excellent	Excellent	Excellent
Fatty acid	4	Excellent	Poor	Poor

Class	TYPE	No. Tested	Acid	Neutral	Basic
Non-ionic	Ethanol	2	Poor	Poor	Poor
Anionic	Petroleum sulphonate	3	Poor	Poor	Poor
"	Fatty acid sulphonate	3	Poor	Poor	Poor
"	Alkyl sulphate	3	Poor	Poor	Poor
"	Sodium taurate	3	Poor	Poor	Poor
Cationic	Primary amine	3	Excellent	Excellent	Excellent
"	Diamine	3	Excellent	Excellent	Excellent
"	Tertiary amine	3	Excellent	Excellent	Excellent
"	Quaternary	4	Fair / Good	Excellent	Excellent
Fatty acid	Talloil	2	Excellent	Poor	Poor
"	Oleic	2	Good	Poor	Poor

Date: June 1976

POLLUCITE EFFECT OF MODIFIERS



1. Poor float with Igepon TE 42
2. Poor float with Nalcamine G 11
3 to 7. Poor float with Retarder LA

Date: June 1976

RESPONSE TO COLLECTORS PYRITE

KEY: Excellent Flotation ■ Fair Flotation [⁘]
Good Flotation ▩ Poor Flotation □

CLASS	No. Tested	Acid	Neutral	Basic
Non-ionic	2	□	□	□
Anionic	12	□	□	□
Cationic	13	□	□	□
Fatty acid	4	□	□	□

Class	TYPE	No. Tested	Acid	Neutral	Basic
Non-ionic	Ethanol	2	□	□	□
Anionic	Petroleum sulphonate	3	□	□	□
"	Fatty acid sulphonate	3	□	□	□
"	Alkyl sulphate	3	□	□	□
"	Sodium taurate	3	□	□	□
Cationic	Primary amine	3	□	□	[⁘]
"	Diamine	3	□	□	□
"	Tertiary amine	3	□	□	□
"	Quaternary	4	□	□	□
Fatty acid	Talloil	2	□	□	□
"	Oleic	2	□	□	□

Date: June 1976

PYRITE

EFFECT OF MODIFIERS

	No Modifier	Fe	Al	F	Starch	Dextrin	Citric Acid
NON IONIC — Ethanol							
Acid							
Neutral							
Basic							
ANIONIC — Petroleum Sulphonate							
Acid							
Neutral							
Basic							
ANIONIC — Fatty Acid Sulphonate							
Acid							
Neutral							
Basic							
ANIONIC — Alkyl Sulphate							
Acid							
Neutral							
Basic							
ANIONIC — Sodium Taurate							
Acid							
Neutral							
Basic							
CATIONIC — Primary Amine							
Acid							
Neutral							
Basic							
CATIONIC — Diamine							
Acid							
Neutral							
Basic							
CATIONIC — Tertiary Amine							
Acid							
Neutral							
Basic							
CATIONIC — Quaternary							
Acid							
Neutral							
Basic							
FATTY ACID — Talloil							
Acid							
Neutral							
Basic							
FATTY ACID — Oleic							
Acid							
Neutral							
Basic							

Date: June 1976

RESPONSE TO COLLECTORS PYROPHYLLITE

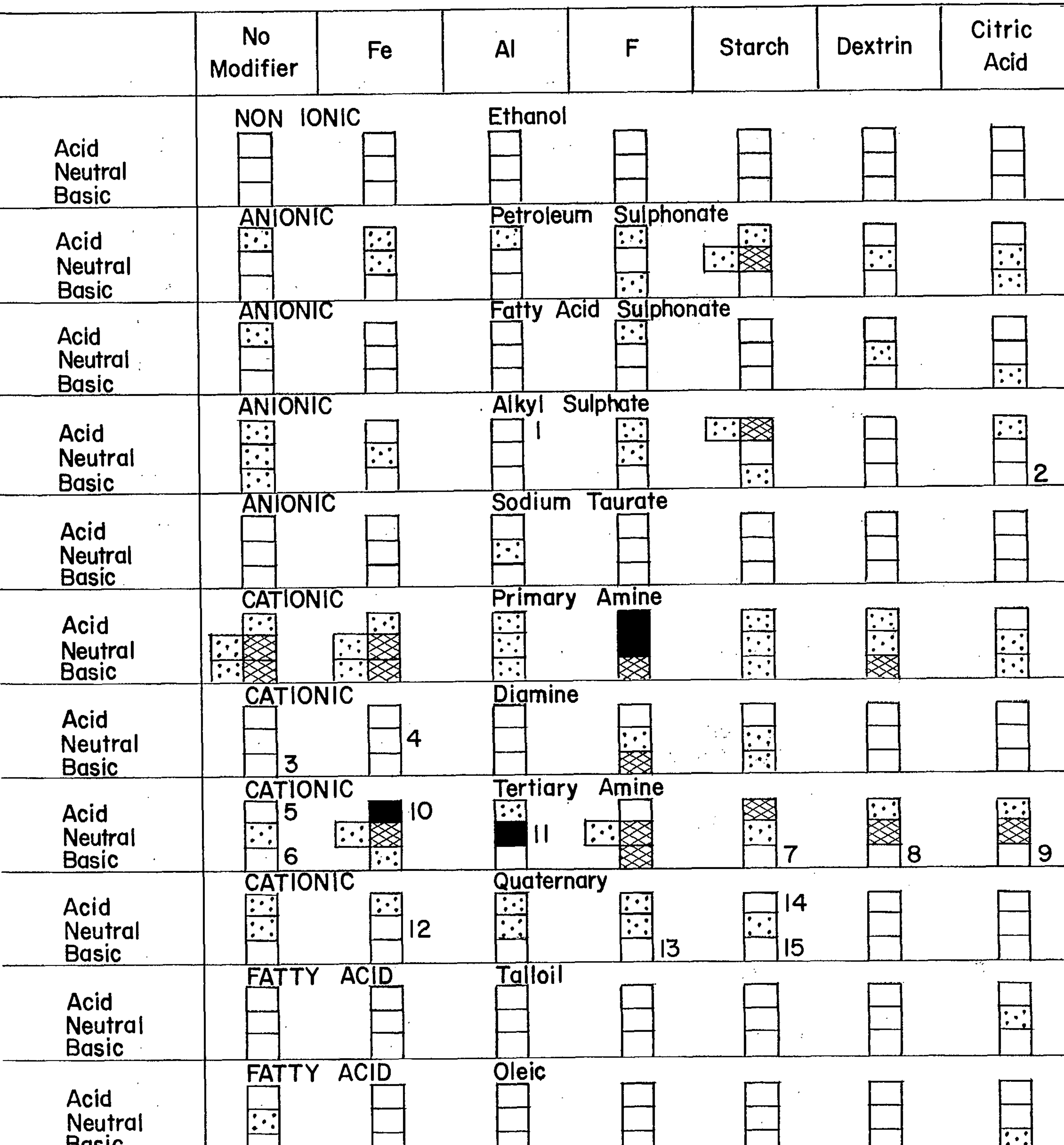
KEY: Excellent Flotation (solid black box) — Good Flotation (cross-hatched box) — Fair Flotation (dotted box) — Poor Flotation (empty box)

CLASS	No. Tested	Acid	Neutral	Basic
Non-ionic	2	Poor	Poor	Poor
Anionic	12	Fair	Poor	Poor
Cationic	13	Poor	Fair	Poor
Fatty acid	4	Poor	Fair	Poor

Class	TYPE	No. Tested	Acid	Neutral	Basic
Non-ionic	Ethanol	2	Poor	Poor	Poor
Anionic	Petroleum sulphonate	3	Fair	Poor	Poor
"	Fatty acid sulphonate	3	Fair	Poor	Poor
"	Alkyl sulphate	3	Fair	Fair	Fair
"	Sodium taurate	3	Poor	Poor	Poor
Cationic	Primary amine	3	Fair	Fair / Good	Fair / Good
"	Diamine	3	Poor	Poor	Poor
"	Tertiary amine	3	Poor	Fair	Poor
"	Quaternary	4	Fair	Fair	Poor
Fatty acid	Talloil	2	Poor	Poor	Poor
"	Oleic	2	Poor	Fair	Poor

Date: June 1976

PYROPHYLLITE EFFECT OF MODIFIERS



1. Excellent float with Duponol 80
2. Excellent float with Duponol 80
3. Excellent float with Duomac C
4. Excellent float with Duomac C
5. Excellent float with Armeen 12D
6. Excellent float with Armeen 12D
7. Excellent float with Armeen 12D
8. Excellent float with Armeen DLM 11
9. Excellent float with Armeen DLM 11
10. Poor float with Nalcamine G 11
11. Poor float with Nalcamine G 11
12. Excellent float with ARQUAD 12
13. Excellent float with ARQUAD 12
14. Excellent float with ARQUAD 12
15. Excellent float with ARQUAD 12

Date: June 1976

RESPONSE TO COLLECTORS PYROXENE

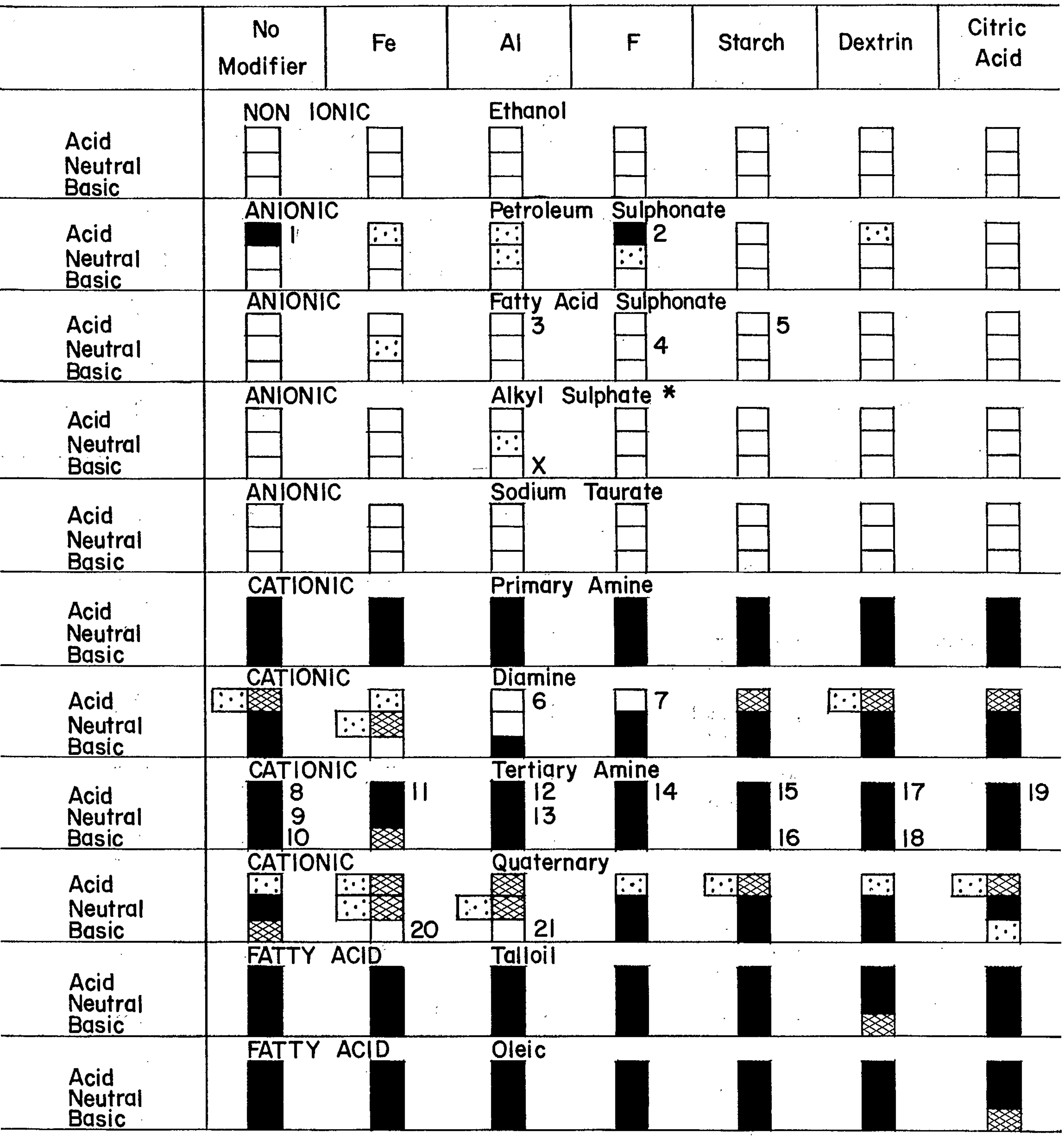
KEY: Excellent Flotation ■ Fair Flotation (dotted)
Good Flotation (cross-hatched) Poor Flotation □

CLASS	No. Tested	Acid	Neutral	Basic
Non-ionic	2	Poor	Poor	Poor
Anionic	12	Poor	Poor	Poor
Cationic	13	Good	Excellent	Excellent
Fatty acid	4	Excellent	Excellent	Excellent

Class	TYPE	No. Tested	Acid	Neutral	Basic
Non-ionic	Ethanol	2	Poor	Poor	Poor
Anionic	Petroleum sulphonate	3	Excellent	Poor	Poor
"	Fatty acid sulphonate	3	Poor	Poor	Poor
"	Alkyl sulphate	3	Poor	Poor	Poor
"	Sodium taurate	3	Poor	Poor	Poor
Cationic	Primary amine	3	Excellent	Excellent	Excellent
"	Diamine	3	Fair / Good	Excellent	Excellent
"	Tertiary amine	3	Excellent	Excellent	Excellent
"	Quaternary	4	Fair	Excellent	Good
Fatty acid	Talloil	2	Excellent	Excellent	Excellent
"	Oleic	2	Excellent	Excellent	Excellent

Date: June 1976

PYROXENE — EFFECT OF MODIFIERS



1,2. Poor float with Leonal SA
3,4,5. Excellent float with Sulphonated Castor Oil
* Good to excellent all cases with Duponol 80, except X
6,7. Excellent float with Duomeen L-11
8 to 19. Poor float with Nalcamine G 11
20,21. Excellent float with ARQUAD 12

Date: June 1976

RESPONSE TO COLLECTORS — SERPENTINE

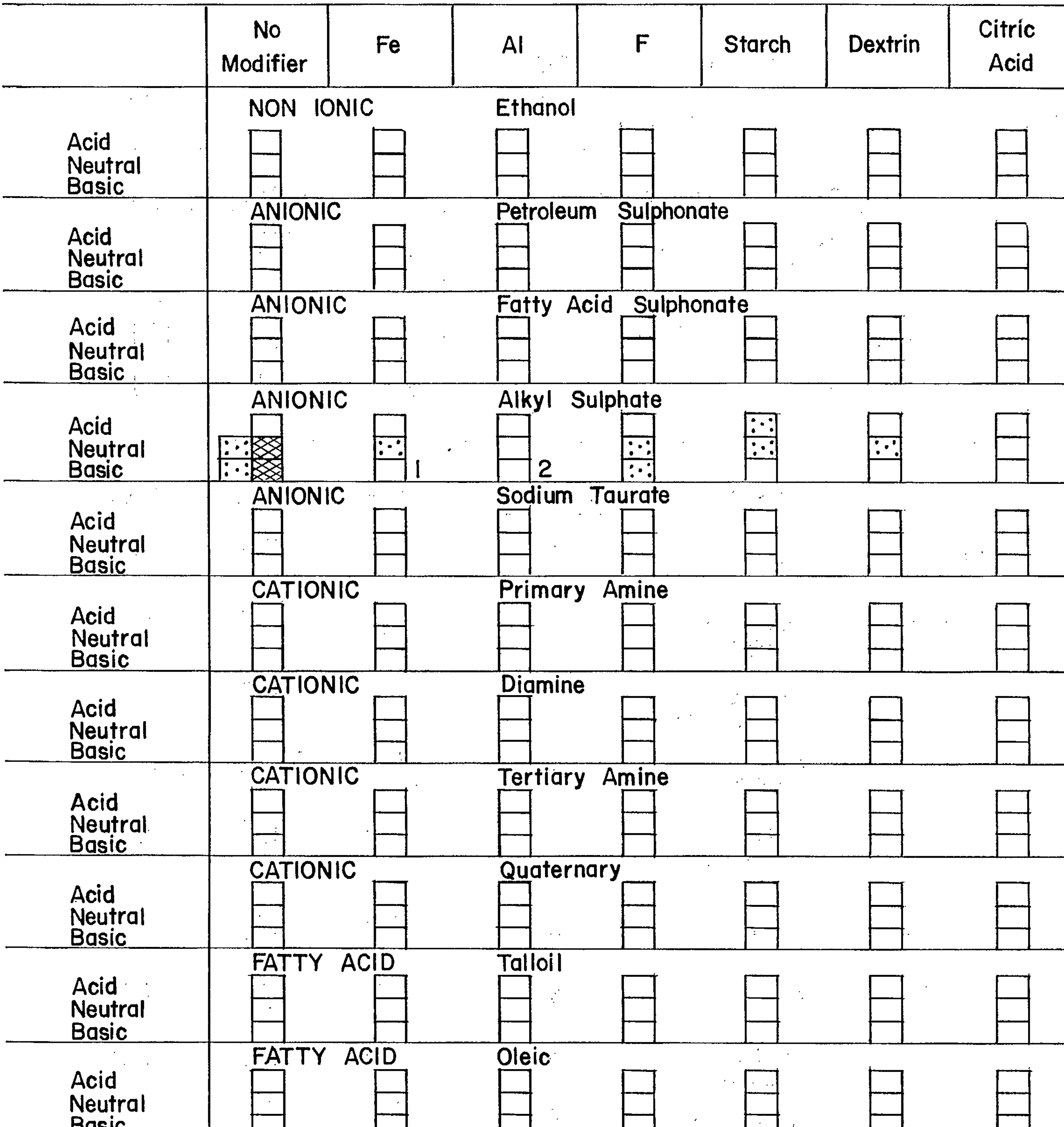
KEY:			
Excellent Flotation	■ (solid)	Fair Flotation	(dotted)
Good Flotation	(cross-hatched)	Poor Flotation	□ (empty)

CLASS	No. Tested	Acid	Neutral	Basic
Non-ionic	2	□ (Poor)	□ (Poor)	□ (Poor)
Anionic	12	□ (Poor)	□ (Poor)	□ (Poor)
Cationic	13	□ (Poor)	□ (Poor)	□ (Poor)
Fatty acid	4	□ (Poor)	□ (Poor)	□ (Poor)

Class	TYPE	No. Tested	Acid	Neutral	Basic
Non-ionic	Ethanol	2	□ (Poor)	□ (Poor)	□ (Poor)
Anionic	Petroleum sulphonate	3	□ (Poor)	□ (Poor)	□ (Poor)
"	Fatty acid sulphonate	3	□ (Poor)	□ (Poor)	□ (Poor)
"	Alkyl sulphate	3	□ (Poor)	Fair / Good	Fair / Good
"	Sodium taurate	3	□ (Poor)	□ (Poor)	□ (Poor)
Cationic	Primary amine	3	□ (Poor)	□ (Poor)	□ (Poor)
"	Diamine	3	□ (Poor)	□ (Poor)	□ (Poor)
"	Tertiary amine	3	□ (Poor)	□ (Poor)	□ (Poor)
"	Quaternary	4	□ (Poor)	□ (Poor)	□ (Poor)
Fatty acid	Talloil	2	□ (Poor)	□ (Poor)	□ (Poor)
"	Oleic	2	□ (Poor)	□ (Poor)	□ (Poor)

Date: June 1976

SERPENTINE EFFECT OF MODIFIERS



1. Excellent flotation with Duponol OS
2. Excellent flotation with Duponol OS

Date: June 1976

RESPONSE TO COLLECTORS SPHENE

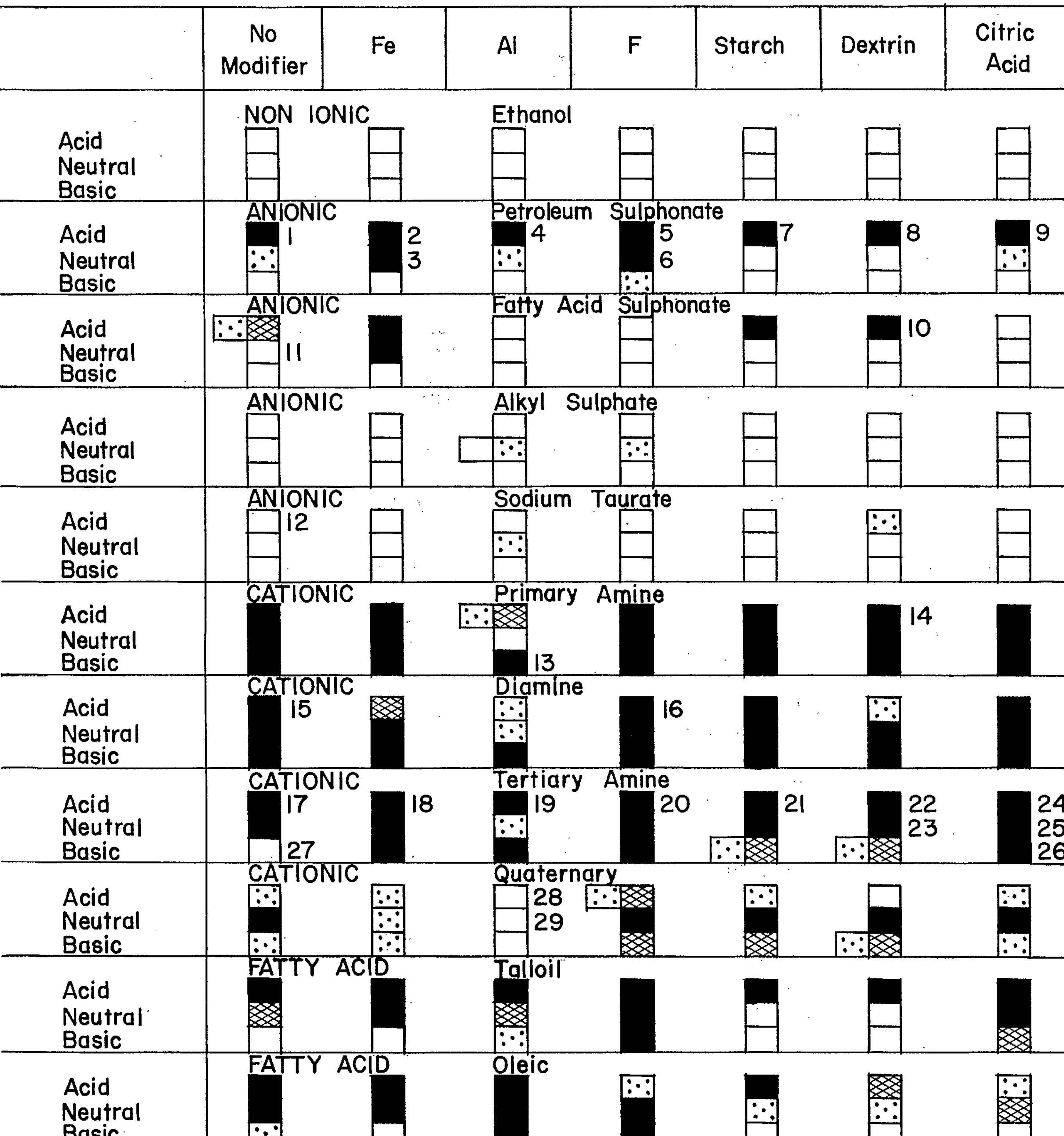
KEY: Excellent Flotation ■ Fair Flotation (dotted)
Good Flotation (cross-hatched) Poor Flotation □

CLASS	No. Tested	Acid	Neutral	Basic
Non-ionic	2	Poor	Poor	Poor
Anionic	12	Fair	Poor	Poor
Cationic	13	Excellent	Excellent	Good
Fatty acid	4	Excellent	Good	Poor / Fair

Class	TYPE	No. Tested	Acid	Neutral	Basic
Non-ionic	Ethanol	2	Poor	Poor	Poor
Anionic	Petroleum sulphonate	3	Excellent	Fair	Poor
"	Fatty acid sulphonate	3	Fair / Good	Poor	Poor
"	Alkyl sulphate	3	Poor	Poor	Poor
"	Sodium taurate	3	Poor	Poor	Poor
Cationic	Primary amine	3	Excellent	Excellent	Excellent
"	Diamine	3	Excellent	Excellent	Excellent
"	Tertiary amine	3	Excellent	Excellent	Poor
"	Quaternary	4	Fair	Excellent	Fair
Fatty acid	Talloil	2	Excellent	Good	Poor
"	Oleic	2	Excellent	Excellent	Fair

Date: June 1976

SPHENE EFFECT OF MODIFIERS



1 to 9. Poor float with Leonal SA
10. Poor float with Emcol 4150
11. Excellent float with Sulphonated Castor Oil
12. Excellent float with Igepon T 33
13,14. Poor float with Armeen L-9
15,16. Poor float with Duomac T
17 to 26. Poor float with Nalcamine G 11
27. Excellent float with Armeen 12 D
28,29. Excellent float with Emcol E 607-40

Date: June 1976

RESPONSE TO COLLECTORS WOLLASTONITE

KEY:

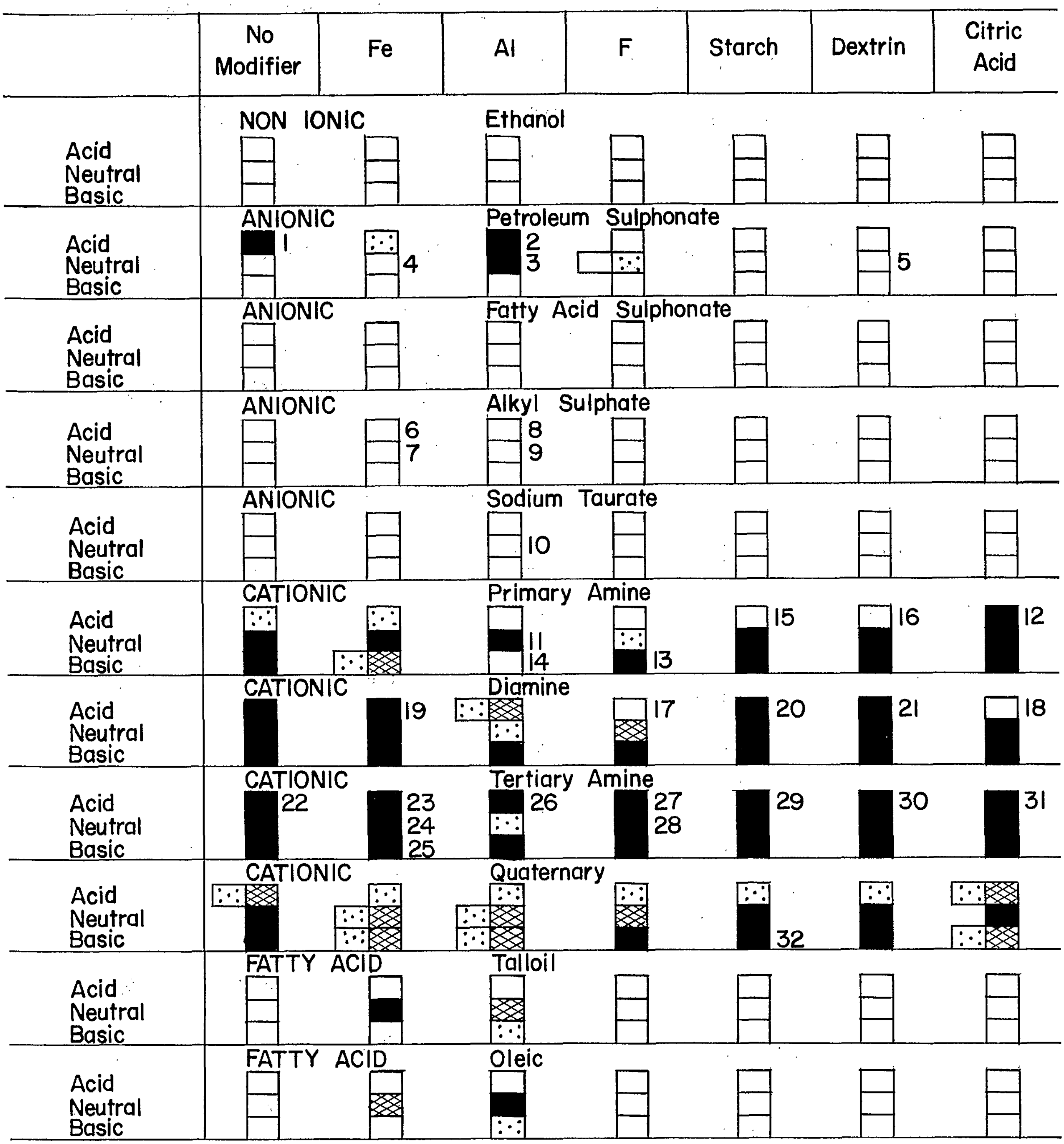
Symbol	Meaning
■ (solid black)	Excellent Flotation
Cross-hatched	Good Flotation
Dotted	Fair Flotation
□ (empty)	Poor Flotation

CLASS	No. Tested	Acid	Neutral	Basic
Non-ionic	2	Poor	Poor	Poor
Anionic	12	Poor	Poor	Poor
Cationic	13	Good	Excellent	Excellent
Fatty acid	4	Poor	Poor	Poor

Class	TYPE	No. Tested	Acid	Neutral	Basic
Non-ionic	Ethanol	2	Poor	Poor	Poor
Anionic	Petroleum sulphonate	3	Excellent	Poor	Poor
"	Fatty acid sulphonate	3	Poor	Poor	Poor
"	Alkyl sulphate	3	Poor	Poor	Poor
"	Sodium taurate	3	Poor	Poor	Poor
Cationic	Primary amine	3	Fair	Excellent	Excellent
"	Diamine	3	Excellent	Excellent	Excellent
"	Tertiary amine	3	Excellent	Excellent	Excellent
"	Quaternary	4	Fair/Good	Excellent	Excellent
Fatty acid	Talloil	2	Poor	Poor	Poor
"	Oleic	2	Poor	Poor	Poor

Date: June 1976

WOLLASTONITE — EFFECT OF MODIFIERS



1,2,3. Poor float with Leonal SA
4,5. Excellent float with Reagent 801
6 to 9. Excellent float with Duponol 80
10. Excellent float with Igepon TE 42
11,12. Poor float with Armac C
13. Poor float with Armeen L-9
14,15,16. Excellent float with Adogen 170A
17,18. Excellent float with Duomeen L-11
19,20,21. Poor float with Duomac C
22 to 31. Poor float with Nalcamine G 11
32. Poor float with Emcol E 607-40

Date: June 1976

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