Chapter 7

THE FRAMEWORK SILICATES

Contents

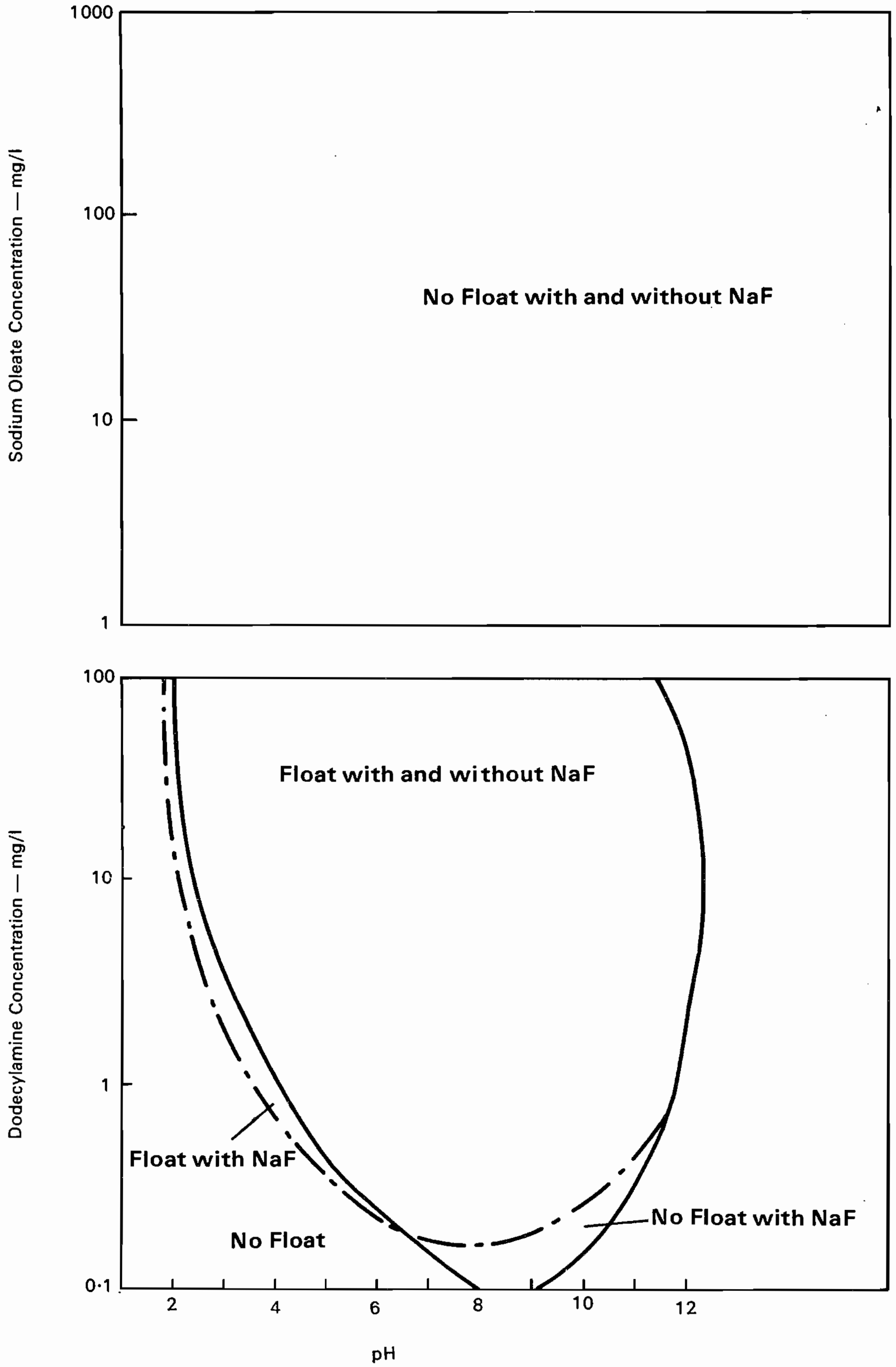

Fig 7.1.1 Feldspar - Albite

7.1 FELDSPAR

COMPOSITION W,Al (Al,Si) Si_2O_8; a continuous three dimensional network of SiO_4 and AlO_4 tetrahedra with positively charged mono- and/or di-valent cations in the interstices of this negatively charged network.

W = Na, K, Ca (and rarely Ba)

Feldspars can be divided into a number of compositional series. Some are shown in Fig 7.1.2. The division of the sodium-calcium feldspars into oligoclase and andesine is arbitrary. There is also an important lower temperature form of the potassium feldspar (K,Na) Al Si_3O_8 microcline.

PHYSICAL PROPERTIES Hardness 6. Specific gravity 2.56 to 2.77. Colour: variable, but mostly white, cream or pink. z.p.c. 1.4 to 1.6[1].

CHEMISTRY Replacement of the surface monovalent cations by hydrogen occurs under the most mild acid conditions[2]. Selective leaching[3] of aluminium from the silicate lattice takes place below pH 4.0.

FLOTATION CHARACTERISTICS The five species of feldspar investigated were albite, orthoclase, anorthoclase, oligoclase and labradorite. No flotation was observed with any of the five in the absence of activating cations using the anionic collector.

The diagram shown for albite (Fig 7.1.1) is typical of the cationic diagrams in most of the feldspars. The optimum flotation pH for albite is 8.0 to 9.0, while that for oligoclase and labradorite is 10.0 to 11.0. The mild activation shown under weakly acid conditions with 20 ppm sodium fluoride was exhibited by all the feldspars. The well known strong activation of feldspars by fluoride at low pH, is obtained with somewhat higher additions.

The cationic diagram for orthoclase (Fig 7.1.3) differs from the others in that the cationic flotation is not very pH sensitive.

FUNDAMENTAL FLOTATION STUDIES

Most of the fundamental work on feldspar flotation has been concerned with the mechanism of fluoride activation at low pH. A number of explanations that have been suggested over the years have included:

(1) Cleaning mineral surfaces by dissolving away amorphous layers[4]

(2) Formation of SiF_6^{2-} in solution, which then re-adsorbs on surface aluminium atoms[5]

(3) Formation of SiF_6^{2-} : amine complex in solution, which absorbs on surface aluminium atoms[5]

(4) Formation of negatively-charged alumino-fluoride complexes at mineral surface[6-8]

(5) Complexing of multivalent potential-determining cations in solution[9]

(6) Formation of a potassium or sodium silico-fluoride layer at the mineral surface. This layer might be expected to be negatively charged in the presence of an excess of potential-determining silico-fluoride ions in solution[9].

Mechanisms 2, 4, 5 and 6 would be expected to lead to an increase in the magnitude of the negative zeta potential at the feldspar surface and hence to increased adsorption of alkyl amminium ions from solution. The increase in zeta potential is certainly observed.

The selective leaching of aluminium from the surface of feldspar by acid treatment is reported to have a marked depressive effect on its cationic flotation. Joy, et al[3] were able to show that this depressive effect was not accompanied by any decrease in amine adsorption. This indicates that amine adsorption is not on aluminium sites over the pH range above 4.0. However they were not able to carry out the investigation over the pH range 2.0 to 3.5, where fluoride activation takes place.

Both Dean and Ambrose[4], and Suliin and Smith[10] observed a minimum in amine flotation in the presence of HF at around pH 3.5-4.0. Suliin and Smith[10] observed a maximum fluoride activation at around pH 2.5. This phenomenon appears to be associated with the presence of molecular HF in solution.

These authors[10] also did some work with $(RHN_2)\,SiF_6$ complex. They observed strong flotation at around pH 5.0, but not around pH 2.0 to 3.0, where one normally observes activation. There is no doubt that this complex does form in the presence of high concentrations of HF and amine[11], but it is questionable whether it forms under practical flotation conditions.

While there is preferential dissolution of aluminium ions, Read and Manser[9] showed that at HF concentrations close to those used in practice the dissolution was near stoichiometric.

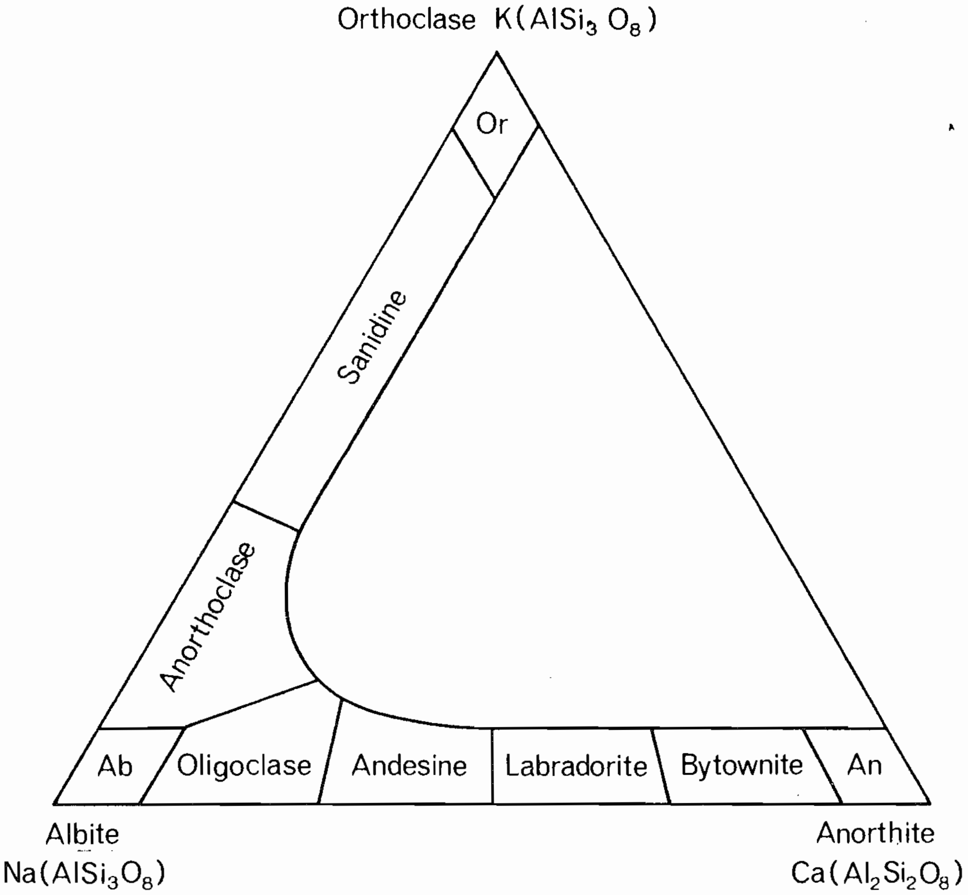

Fig 7.1.2 **Compositional Series of Feldspars**

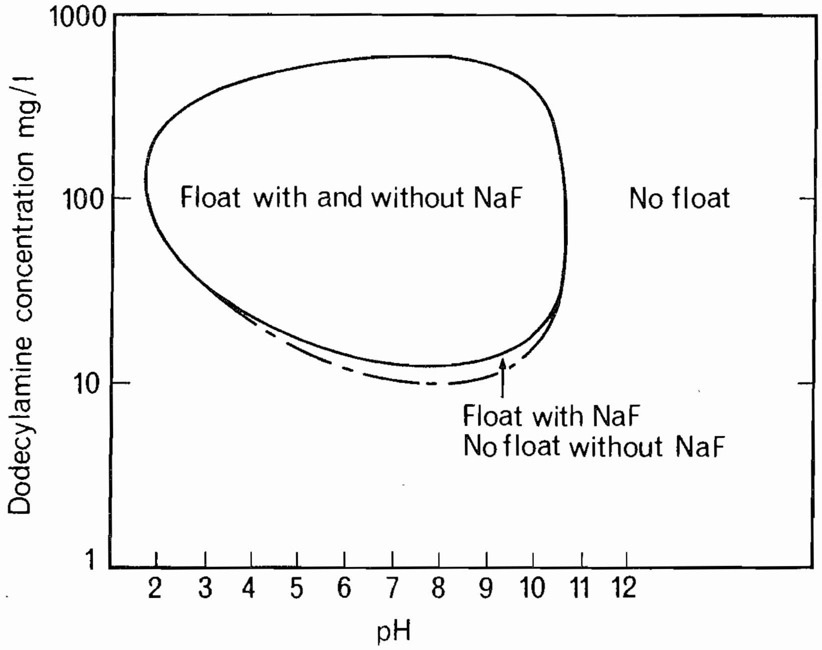

Fig 7.1.3 **Feldspar - Orthoclase**

They examined the ionic equilibria between the species in the flotation pulp. This indicated that the fluoride level required to activate feldspar was greatly in excess of that required to complex all the ferric iron and aluminium in solution, and sufficient to form considerable amounts to silico-fluoride ions. The potassium concentration in flotation pulps was low, indicating the formation of some insoluble potassium compound in the system.

PRACTICAL FLOTATION SYSTEMS

The main application of flotation in the production of feldspar concentrates is in the treatment of pegmatites and granites, where the problem is to remove the feldspar from quartz, mica and other ferruginous impurities. The ores currently treated are mainly rich in potassium feldspars and poor in plagioclase.

The mica is normally removed first. One method is to float the mica under acid conditions with a small amount of amine. Eddy et al[12] obtained optimum removal at pH 2.3 using 0.25 kg/t coco-amine (average chain length C_{12}) with 0.48 kg/t kerosene and 0.12 kg/t MIBC. Optimum removal was also obtained at pH 4.6. This treatment might also be expected to remove any feldspar weathering products. O'Meara et al[13] used 0.16 kg/t triamyl amine in an acid circuit for this purpose. Gieseke[14] has patented the use of petroleum sulphonate in an acid circuit for mica removal.

The other principal method for mica removal is a cationic/anionic float at pH 9.0 to 10.0; a combination of sodium carbonate and lignin sulphonate is used to depress the quartz and feldspar[15]. Eddy et al[12] got equally good results with both methods of mica removal. Their alkaline mixed-collector method was similar to that described in the section on muscovite, except that lignin sulphonate was used instead of sodium silicate as a gangue depressant/dispersant. The oleate/amine ratio was around 5:1.

Once the mica and ferruginous impurities have been removed, the feldspar is then floated from the quartz. Feldspars are inherently more floatable than quartz under acid conditions[13]. However this difference can be greatly accentuated over the pH range 2.0 to 3.5, by the addition of HF. This method was developed around 1939,[13,16] and is, with slight modifications, still the major method for feldspar flotation.

A typical method is given by Eddy et al[12]. After the mica float, the tailings were deslimed to remove the -40μm material, then conditioned for 8 minutes with 1.7 kg/t HF, 2.0 kg/t tallow (C_{18}) amine acetate, 0.16 kg/t MIBC and 0.49 kg/t fuel oil for 8 minutes. In order to obtain commercial-grade feldspar and quartz it was necessary to pass these products through a wet magnetic separator.

The amount of HF required depends on the type of ore – addition levels between 1-9 kg/t are quoted[17]. If the feldspar is pure and unaltered it can be activated[4] with only small amounts of HF but weathered feldspar requires larger quantities. This is not surprising since part of the action of the HF is to clean the mineral surface and to disperse the weathered products.

Commercial HF is reported to be more efficient than pure HF as a feldspar activator, possibly due to silicofluoride impurities[13]. Some workers have used sodium fluoride with sulphuric acid and others[18] ammonium bifluoride/sulphuric acid combinations, instead of HF, with satisfactory results. Softened water is sometimes used[17]. This may be particularly necessary at high HF additions, since high calcium concentrations in the water may lead to calcium fluoride precipitation.

Although feldspars are not readily floated by anionic collectors, they may be activated by cations in a similar manner to quartz[19]. Microcline is readily activated by ferric iron under slightly acid conditions and by calcium at high pH (10.0 to 11.0). This activation can be inhibited by the use of suitable anionic complexing agents[19,20]. The question of depression of the network silicates is fully discussed in the section on quartz (Section 7.4).

DIFFERENTIAL FELDSPAR FLOTATION

Microcline and albite are commercially the most important feldspars. These are normally recovered from ores rich in the particular feldspar and hence differential feldspar flotation is not necessary. However the earliest workers[13] in this field observed that the plagioclase feldspars were more reluctant to float than the sodium and potassium members. They[13] observed that the plagioclase feldspars, tended to be recovered in the scavengers rather than the roughers. Within the plagioclase the sodium feldspar,albite,is more readily activated by HF than is the calcium-rich end member,anorthite[21].

Yanis[22] has claimed that it is possible to depress the amine floation of a sodium feldspar with either magnesium or calcium ions and thereby concentrate the potassium feldspar. His starting material was a mixed feldspar flotation concentrate, obtained in the usual way with HF and amine.

Starikova[23] was able to increase the potassium content of the feldspar concentrate by carrying out the fluoride activation in the presence of 15 g/l sodium chloride. Revnivtzev et al[24,25] have shown that potassium and barium ions would depress potassium feldspars during the flotation of plagioclase. The cations used had similar radii to those in the feldspar they depressed. The electrolyte additions were rather high, particularly if the minerals have not been pre-treated with HF. Treatment by HF both increases selectivity and decreases the concentration of cation depressant required.

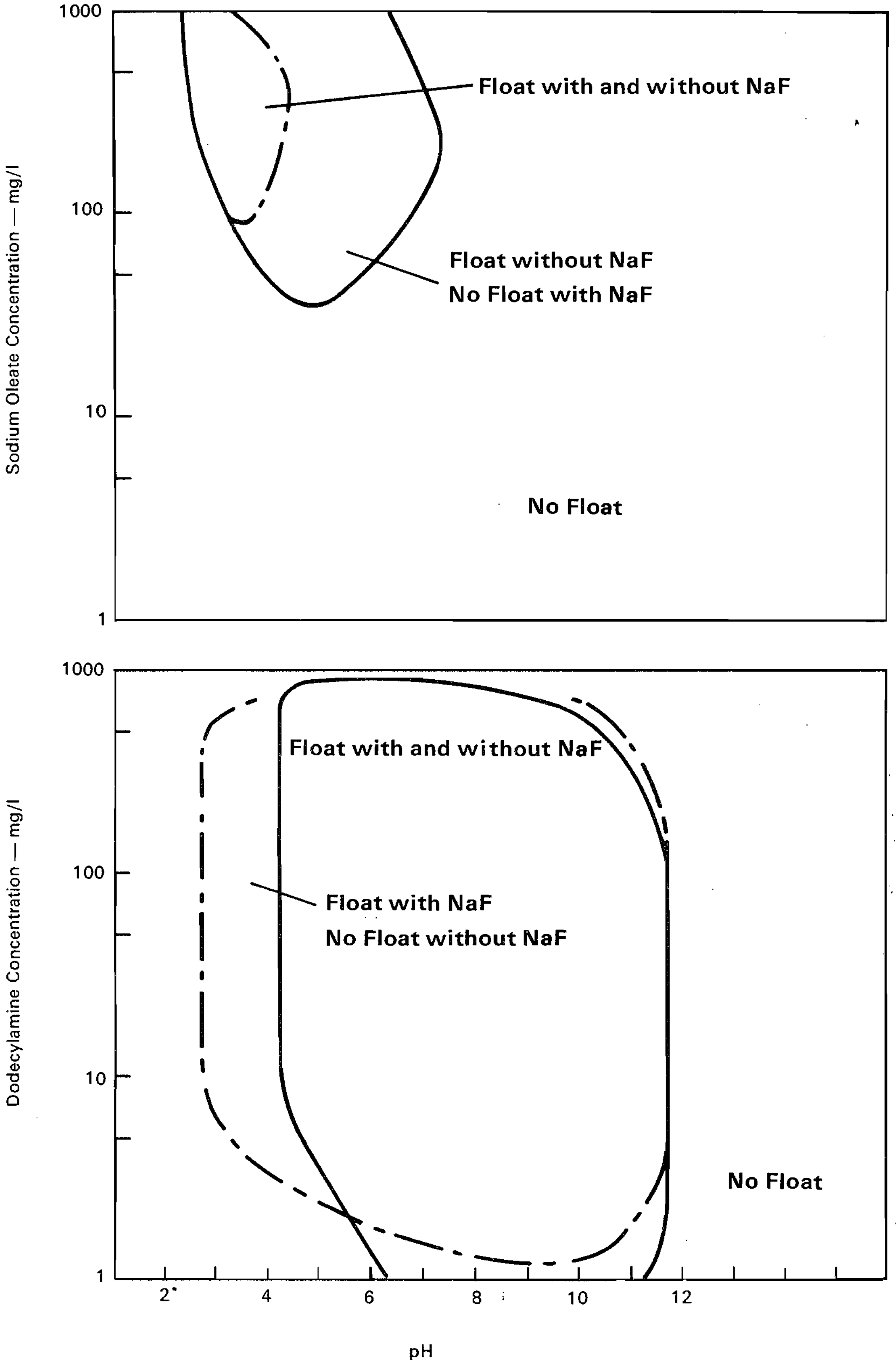

Fig 7.2 Nepheline

7.2 NEPHELINE

COMPOSITION $Na_3K[Al_4Si_4O_{16}]$, an alkali network silicate in which approximately half the silicon atoms have been replaced by aluminium atoms, a feldspathoid.

PHYSICAL PROPERTIES Hardness 5.5 to 6.0. Specific gravity 2.5 to 2.7. Colourless, grey or white hexagonal crystals.

CHEMISTRY Nepheline is partially soluble in hydrochloric acid leaving a gelatinous silica residue.

FLOTATION CHARACTERISTICS The cationic flotation characteristics of this mineral are similar to those of the feldspar class with the exception that the fluoride modifier has a more marked effect at acid pH values. The flotation diagram appears as Fig 7.2.

The existence of an anionic flotation area for a network silicate mineral is unusual, but its position with respect to pH together with the strong depressant effect of the fluoride ion suggests that this may be due to cation activation – see text below.

PRACTICAL FLOTATION SYSTEMS

A considerable volume of research has been carried out by Russian workers on the flotation of ores containing nepheline but there is no clear-cut distinction between fundamental test-work and practical processing of ores. No division has therefore been attempted here.

Flotation of minerals from nepheline

The majority of papers dealing with aspects of nepheline flotation describe the exploitation of the apatite-nepheline deposits of the Russian Kola peninsular. The apatite produced there forms the basis for the phosphate fertilizer industry whilst the nepheline is used as a raw material for the Russian aluminium industry. Typical of the ores of this district are those at Khibiny[26] which were mined as long ago as 1932. At that time the ores were reported to have contained between 60 and 70 per cent apatite together with 30 to 20 per cent nepheline. Separation of this apatite was achived by means of flotation using peat tar as the collector under alkaline conditions. Nepheline and other silicate minerals present were depressed with sodium silicate. In 1969 the combined beneficiation plants in this area, processing 26 million tons of ore, were claimed[27] to be amongst the world's largest. A mixture of distilled and raw tall oils together with oxidized petroleum is now used as the flotation collector. Other collectors that have been described for the apatite flotation stage include a 1:1 mixture of saponified fatty acid residues, together with a neutral oil[28], tall oil fatty acids alone[29], synthapone CP (sodium cetyl and oleyl sulphates), n-lauryl sulphonate[30], IM 50 and ANP[29]. Various silicate depressants have also been used, depending upon the nature of the minor constituents present in the ore body being tested. For example, lead acetate has been used[29] for the depression of sphene, aegerine and titano-magnetite as well as nepheline. Sodium silicofluoride[31, 32] was found to be satisfactory in depressing nepheline alone whilst floating minor iron minerals.

Sodium hexametaphosphate[33] has been used to depress nepheline when floating pyrochlore from a nepheline-syenite using anionic collectors. Further details of work carried out on collector/modifier systems involving flotation of various titanium and iron minerals from nepheline will be found in Section 4.1 of this book.

An investigation into the effects of sodium sulphide on the adsorption of oleic acid on to nepheline has been carried out by Eropkin and Koval[34] using radio-isotope techniques. They found oleic acid to be very strongly adsorbed between pH 9.0 and 12.0 but that flotation could be depressed by the addition of sodium sulphide. This caused displacement of the collector by sulphide ions which, in turn, were more strongly adsorbed on to the mineral surface. It is also suggested by these authors that the anionic collector adsorption on to nepheline is due to calcium or magnesium cation activation and that, as the concentration of these ions increases, the effects of the sodium sulphide modifier are decreased. The anionic flotation areas of this mineral as determined at Warren Spring Laboratory, that are shown in Fig 7.2, are of the type normally obtained when cationic activation has taken place (i.e. a limited flotation area over a narrow pH range together with high sensitivity to modifiers). This is in agreement with the above observations. The addition of sodium sulphide to the grinding circuit in order to depress nepheline has also been described[35].

Separation of nepheline from feldspar

Workers at Warren Spring Laboratory[36] have obtained satisfactory separations of nepheline from feldspar whilst separating a series of mineral species for geological age determinations. Using a cationic collector together with a fluoride modifier it was found possible to obtain a high-grade nepheline concentrate at about pH 2.5. To use what is accepted as the standard method for the flotation of feldspars for the flotation of a feldspathoid from a feldspar, would initially appear to be incongruous. However, when the nepheline and feldspar flotation diagrams given in this publication are compared, it will be seen that the former is considerably more sensitive to additions of the fluoride modifier under acid conditions when using a cationic collector.

A similar separation has been described by Czygan[37] who obtained 90 per cent nepheline concentration by using amine collector in a circuit adjusted to pH 3.5 to 4.0 with hydrofluoric acid. In this separation sodium hexametaphosphate was also used as a modifier together with amyl alcohol frother.

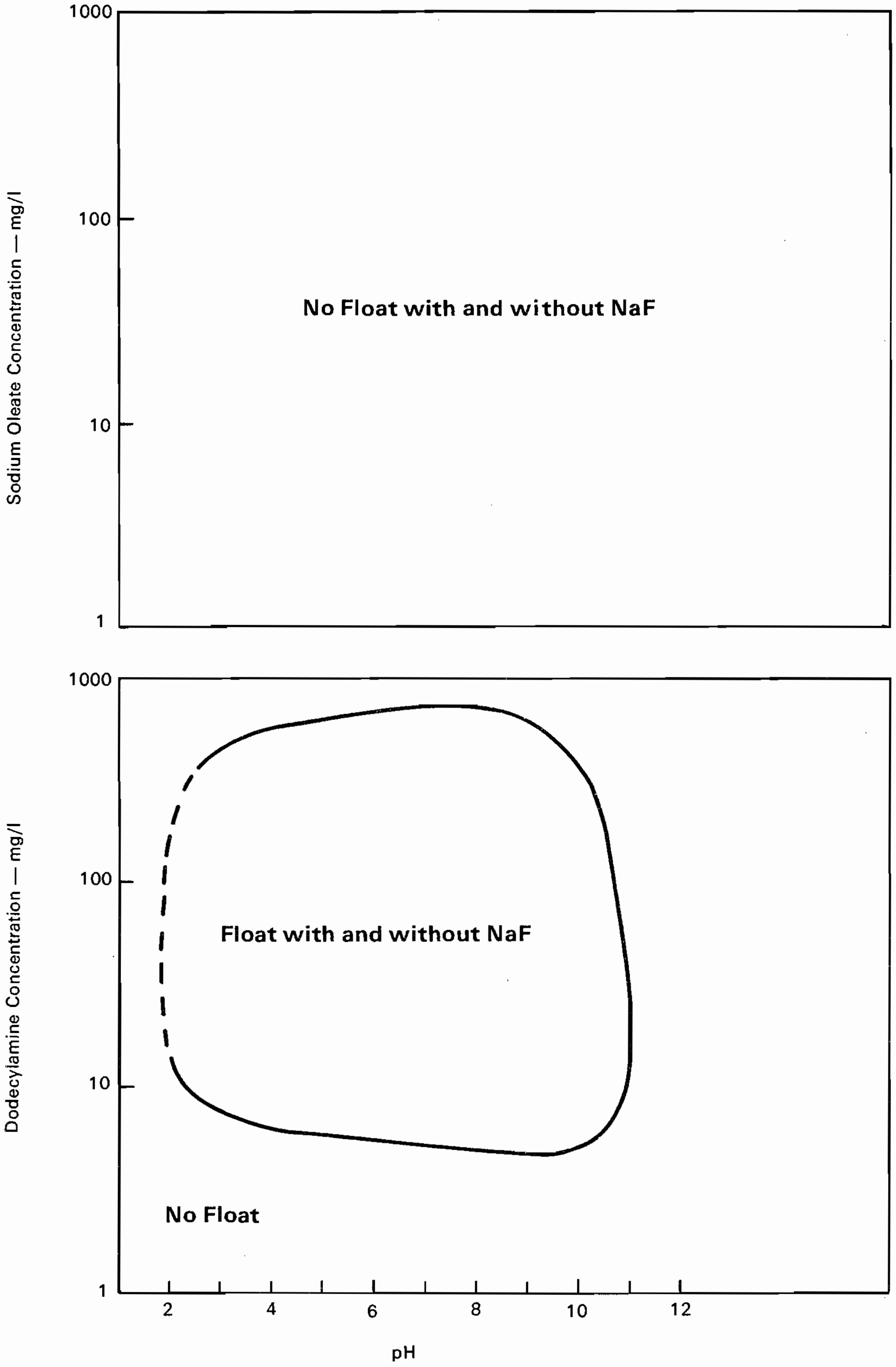

Fig 7.3 Petalite

PETALITE

COMPOSITION $Li[AlSi_4O_{10}]$, lithium aluminium silicate.

PHYSICAL PROPERTIES	Hardness 6.0 to 6.5. Specific gravity 2.4. Grey-white or pink monoclinic crystals.
CHEMISTRY	Insoluble in acids except HF.
FLOTATION CHARACTERISTICS	No flotation of petalite was observed over the complete pH range when using up to 1000 mg/l of the anionic collector sodium oleate, either in the presence or absence of sodium fluoride modifier. Good flotation was obtained with the dodecylamine collector, with very little sensitivity to change in pH between 2.0 and 11.0. The area of flotation determined with this collector in the presence of the fluoride modifier was exactly similar to that obtained in its absence. The flotation diagram appears as Fig 7.3.

FUNDAMENTAL FLOTATION STUDIES

The flotation properties of petalite using laurylamine[38] and sodium oleate[39] have been investigated by Russian workers. The effectiveness of the cationic collector was similar to that found at Warren Spring Laboratory. Amine adsorption, determined by the use of radioisotope techniques, was found to be a maximum between pH 7.0 and 10.0 although the surface was shown to be most hydrophobic between pH 6.0 and 10.0. The addition of either sodium silicate or silicofluoride to the pulp decreased collector adsorption on the mineral surface but the effect of this on the flotation characteristics is not reported.

Although, by using similar techniques, sodium oleate was shown to be adsorbed to a considerable extent on the petalite surface, only just over 10 per cent of the mineral was found to float with this anionic collector. Activation with ferric or aluminium ions, however, caused the flotation extraction to increase up to 90 per cent. Sodium silicofluoride was shown to be an effective depressant for this cation-activated petalite.

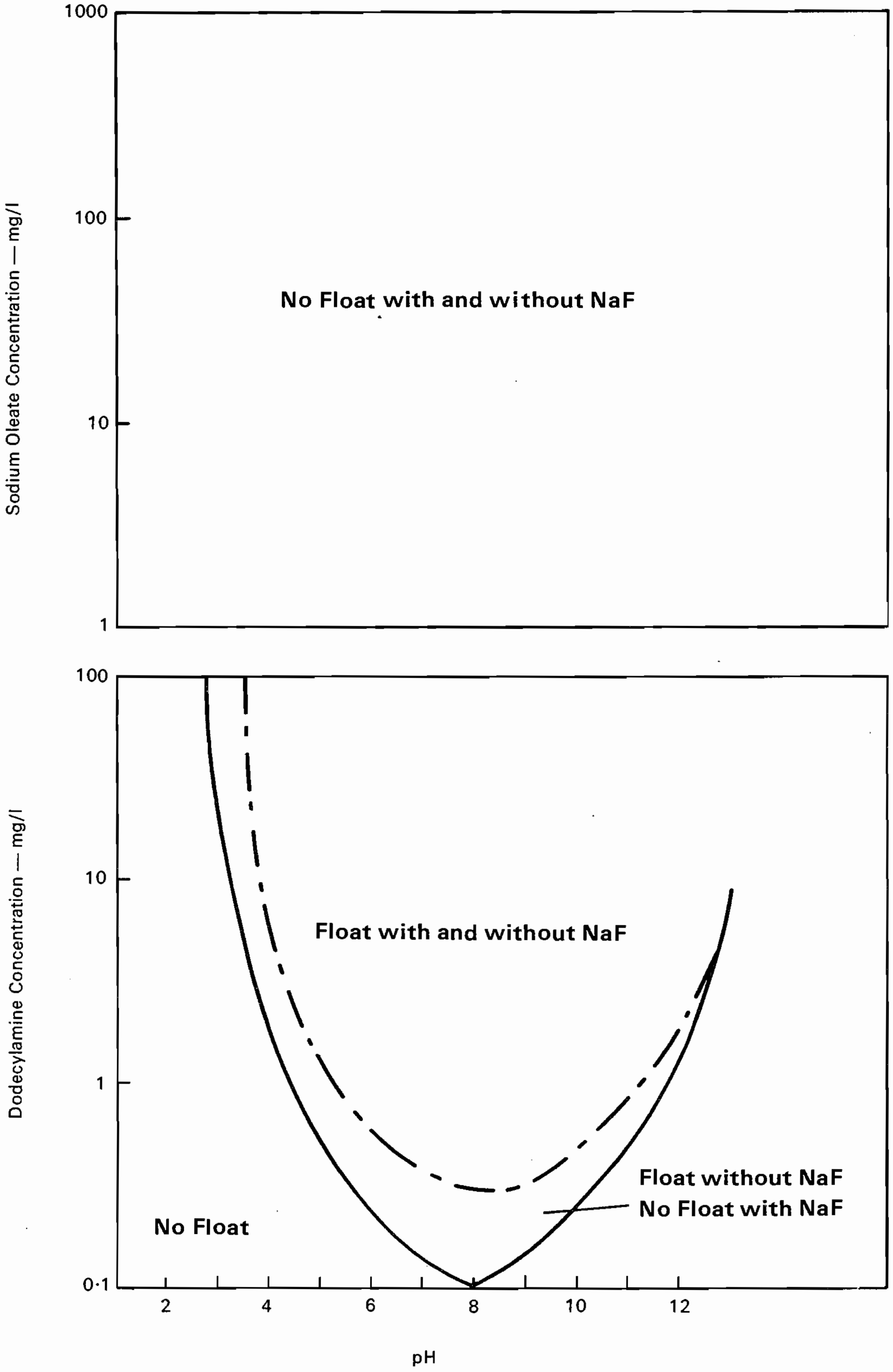

Fig 7.4 Quartz

7.4 QUARTZ

COMPOSITION SiO_2, silicon dioxide, silica.

PHYSICAL PROPERTIES	Hardness 7. Specific gravity 2.65. Colourless or white trigonal crystals. The presence of impurities can lead to a variety of other colours. z.p.c. 1.3 to 3.7[40-45].
CHEMISTRY	Insoluble in acids except concentrated HF.
FLOTATION CHARACTERISTICS	Clean quartz, with no activator present, does not float with sodium oleate in the presence or absence of the fluoride ion. Quartz floats well with only trace quantities of amine over a range of pH values from 3.0 to 13.0 with an optimum between 7.0 and 9.0. Fluoride ion has a depressant effect which is more marked under acid conditions. The flotation diagram appears as Fig 7.4.

FUNDAMENTAL FLOTATION STUDIES

The effects of various multivalent cations on the flotation of quartz with anionic collectors have been studied in detail by many workers. It is commonly accepted that, except at very acid pH values, quartz has a high negative surface charge and that charge reversal must be accomplished before flotation with anionic collectors can take place. For example, by the determination of zeta potentials, Mackenzie[46] has shown quartz to have a positive surface between pH 2.0 and 8.0 in the presence of ferric ions and a positive surface between pH 7.0 and 11.5 in the presence of bivalent nickel or cobalt ions[47]. Using similar techniques other workers[48] have shown the quartz surface to be positive between pH 3.0 and 8.5 in the presence of aluminium ions, between pH 5.0 and 12.0 in the presence of lead ions and at pH values greater than 10.0 in the presence of magnesium ions.

From a practical viewpoint the two most important activating cations that commonly occur in flotation pulps are calcium and iron. The former results mainly from the use of hard waters in flotation circuits and the latter may arise from contamination but, more important, out of the iron minerals from which a separation is frequently desired. An outline of some of the fundamental investigations on these two cations and their mode of activation is given below, but for further information on other activating species which are considered to be outside the scope of this present work, a selected bibliography is given at the end of this chapter.

Calcium activation

The fact that quartz may be activated with calcium ions and subsequently floated with anionic collectors under alkaline pH conditions has been known for over 40 years[49]. Practical use has been made of this phenomenon for at least 25 years in the reverse flotation beneficiation of ion ores[50].

A very considerable volume of research has been carried out by many workers into the mechanism of this activation, not only by calcium but also by other multivalent cations. For example, Cooke and Digre[51,52] have postulated that as the pH value is increased, calcium ions first exchange for hydrogen ions on the quartz surface and then at very high pH values calcium is replaced by sodium ions. (This theory is supported by the work of Yanis[53] who showed that calcium ions can be removed from silica surfaces either by rinsing with water at pH 6.0 to 7.0 or by exchange with sodium chloride solution.) They also showed that the optimum conditions for calcium ion activation occurred at pH 11.5, this being the pH at which the minimum quantity of calcium necessary for activation was required.

Using the isotope ^{45}Ca, Canadian workers[54] have determined the adsorption of calcium on to quartz over the pH range from 4.0 to 12.0. They found that the very low adsorption at pH 7.0 increased rapidly at pH 10.0 and reached a maximum at about pH 11.5. A sharp drop in calcium ion adsorption found above pH 11.5 was followed by another increase at pH 12.0 and above. The authors suggest that this increase at very high pH levels was caused by the formation of colloidal silicic acid which was followed by the precipitation of calcium silicate on the quartz surface. Again using radiochemical techniques, Russian workers[55] have determined the adsorption of calcium ions and sodium oleate at both the quartz/solution interface and at the solution/air interface under varying concentrations of sodium hydroxide. The onset of flotation at pH 11.0 was found to coincide not only with adsorption of calcium at the quartz surface but also with an increase in calcium ion concentration at the solution/air interface. At the same time there was a reduction of sodium oleate at the solution/air interface of a higher order than that accounted for by adsorption on to the quartz surface. The authors concluded that the mechanism of cation activation was thus related to both the fixation of collector on to the surface via calcium adsorption and to the formation of a rarefied film of calcium oleate compounds on the bubble surface causing an enhancement of the attractive forces between particle and bubble.

A series of papers by M.C. Fuerstenau[56-58] and others have reported on investigations into the flotation of quartz with a number of anionic collectors in the presence of multivalent cation activators. The authors postulate that a basic hydrated complex of the collector and the activating cation is responsible for flotation under these conditions. Subsequent studies by Malati and Estefan[59,60] and by Clark and Cooke[61] have led these authors also to conclude that the hydroxyl ion plays an important part in cation activation. However, this theory has been questioned by Watson and Kitchener[62] during a discussion on metal ion hydrolysis and surface charge in beryl flotation.

Iron activation

Both Russian[63] and American[64] workers have shown that the quantity of iron introduced into a pulp during the grinding process is sufficient to activate quartz for flotation with anionic collectors. The reported pH range over which ferric iron activation occurs varies from author to author. For example, Schuhmann and Prakash[65] found that quartz may be floated from pH 3 upwards when using fatty acid collectors, whereas Fuerstenau[64] and his co-workers obtained a maximum flotation recovery between pH 1.0 and 5.0 when using a sulphonate collector with hydrochloric acid as a pH modifier. Eigeles and Volva[66], on the other hand, claim that fatty acid flotation of quartz is possible even in a neutral medium if it has previously been activated with either ferrous or ferric ions.

Other Russian workers[67] have made a study of the conditions under which iron adsorbs on to a quartz surface and also the floatability of this activated quartz over a range of pH values using oleic acid as the collector. These authors found that, although the maximum adsorption of iron occurred at neutral pH, the maximum floatability of the quartz so activated occurred in a weakly alkaline medium. The data given by Eigeles[68] for the adsorption of a ferric oxide hydrosol on to quartz shows a maximum at pH 8.0, a value which is more in agreement with the flotation data, than the adsorption data of the above workers.

It has been shown that quartz samples which have adsorbed iron ions may be subsequently deactivated by the addition of various complexing reagents. Those listed in the literature include sodium sulphide[62,69], ferricyanide[67], citrate and tartrate as well as cyanide, hexametaphosphate, and sodium silicate[70].

PRACTICAL FLOTATION SYSTEMS

The final process for the concentration of various oxide iron minerals involves the reverse flotation method where the gangue minerals, mainly quartz, are floated whilst the iron minerals are depressed. The gangue minerals may be floated using either a cationic collector or an anionic collector together with a multivalent cation activator such as a calcium salt.

Separation of silica from iron minerals using cationic collectors

A comparison of various amine collectors for the flotation of silica from magnetic iron ores has been made by Hedberg[71]. Using coco primary amine acetate as a standard it was shown that lauryl amine acetate was a more efficient collector whilst remaining equally selective. (More efficient was defined by this author as increased recovery of silica in the concentrate.) The tallow homologue was equally selective but less efficient than the standard. Coco-oleyl- and tallow-diamines were all more selective, the former being more efficient, but the latter two less efficient, than the standard. Trimethyl alkyl ammonium chloride compounds were found to be even more selective but less efficient than either the mono- or the di-amines. However, Rykov and Rykova[72] found quaternary ammonium chlorides to have a high collecting capacity for quartz with a maximum flotation recovery in slightly acidic or neutral media. Although magnetite was floated in an alkaline medium, an effective separation of quartz was carried out by using a low collector concentration at neutral pH, without the need for further modifiers. The same workers also report[73] the use of short-chain (C_7 to C_9) amine collectors at pH 8.5 to 9.5, for the effective removal of trace quantities of quartz from iron ores, again without the use of further modifiers.

Most separations of quartz from iron ores utilize reverse flotation techniques but involve the addition of modifiers, the most common of which is starch or a starch derivative. For example hematite, martite and hydrolysed iron oxides were shown by Canadian workers[74] to be depressed by starch at alkaline pH values. Although the extent of amine adsorption on martite and quartz has been shown[75] to be unaffected by the addition of starch, the flotation of martite was subsequently shown to be strongly depressed by the addition of only 50g of starch per tonne of ore treated. The combined use of starch and calcium ions was found to give the most effective modification in another case[76].

A German process[77] uses additions of starch of up to 300 g/t to depress iron oxides whilst floating silicates and carbonates between pH 8.0 and 10.0 from iron ores. This employs cationic or anionic collectors either singly or simultaneously.

Separation of silica from iron minerals using anionic collectors

The flotation of quartz by anionic reagents over large pH ranges in the presence of activating ions such as calcium, magnesium and iron has already been discussed. Iron minerals may also be floated by similar anionic collectors under both acid and alkaline conditions, but are claimed[78] to be strongly depressed by starch, particularly at high pH values. This principle is used for the beneficiation of iron ores using starch[79, 80] and various similar compounds[81] to depress the iron minerals whilst removing silica gangue as a froth product.

Depression of activated quartz during anionic flotation

The choice of a depressant for cation-activated quartz will depend upon both the minerals present from which the separation is desired, and the activating ions present. For example, low concentrations of oxalic acid, alizarin and pyrocatechol were found[82] to be effective modifiers when floating hematite from activated quartz. These three modifiers used in conjunction with sodium oleate collector gave iron recoveries of about 90 per cent with grades of between 50 and 60 per cent. Similar recoveries were obtained when using triethanolamine, sodium diethyl-dithiocarbamate, β-nitroso-γ-naphthol, and cupferron as the modifying agents. However, in these cases, higher additions of reagent were necessary in order to achieve acceptable grades of concentrate. The action of these depressants was attributed by the authors to be due to the removal of the activating iron from the quartz surface.

Volva and Eigeles[83] have shown sodium sulphide to be a strong depressant for quartz that has been previously activated by iron. It was still effective even if added after the surface had been conditioned with oleic acid collector and as such could be utilized in cleaning circuits where it is desired to remove traces of activated quartz. If the activation was due to calcium or magnesium ions, sodium sulphide was found to be ineffective and it became necessary to use sodium silicate in this case[84].

Citric acid also has been successfully used for the depression of activated quartz at pH 7.5 during the anionic flotation of kyanite from a kyanite-quartz mica schist[85] and an American kyanite-quartzite[86].

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I STRONTIUM

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J TIN

See reference: 2

K ZINC

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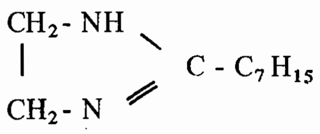
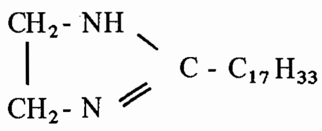
APPENDIX

RUSSIAN FLOTATION REAGENTS

It is common practice amongst workers in the field of flotation to refer to their reagents by a trade name. For example, ‘Armac C’, ‘Aerosol 22’, ‘Dow 250’, ‘Igepon A’, ‘Lissapol LS’ etc. Whilst most of these will be familiar to Western workers, the composition of flotation reagents used in countries of the Eastern bloc are, at times, difficult to assess. Authors of papers on flotation should take note that their work will be of universal interest only if the composition of the collectors used is defined. There can be little doubt that a Russian worker would have as much difficulty in finding the composition of, say, ‘Aerosol 22’ as an America worker would have in trying to determine the composition of, say, ‘IM 50’. The name of neither of these two reagents gives any indication to the prospective user even of the functional group present.

During the production of this handbook many papers from Eastern bloc countries have been referred to and it has become possible at least to suggest the probable composition of some of the more common flotation reagents used. These reagents are listed in this appendix.

AB 1	Allyl ether of Butyl xanthic acid
ANP series	These are mono-amines or their hydrochlorides produced by the reduction of technical nitro-paraffins. i.e. Amino Nitro Paraffin.
ANP 1	A mixture of amine hydrochlorides with an average carbon chain length of 14.
ANP 2	Similar in composition to ANP 1 but produced from a mixture of C_{12} to C_{18} paraffins with an average carbon chain length of 15.
ANP 14	Pure C_{14} amine or amine hydrochloride.
Azolyat A	An Alkyl-aryl sulphonate containing C_6- alkyl chain.
D 3	Dimethyl phthalate frother.
DS-8	Non-ionic surface active agent produced by the reaction of ethylene oxide with tetradecanol. The average extent of oxyethylation is 8 with a hydrocarbon chain length of 14.
DS-RAS	Sodium alkyl aryl sulphonate.
I-K	Ethylene diamine condensate of caprylic acid. 
INKhP-9	A biodegradable mixture of mono-, di- and tri-alkyl aryl sulphonates.
I-O	Ethylene diamine condensate of oleic acid. 
IM Series	This is the series of reagents developed by the central Russian Institute Mekhanobra or flotation institute.
IM 6-8	Frother C_6 to C_8 alcohol mixture.

IM 11	C_{12} amine or amine hydrochloride.
IM 12	C_{12} amine acetate.
IM 21	Linseed oil soaps.
IM 50	Collector. Soluble salt of hydroxamic acid synthesized from C_7 to C_9 carboxylic acids or metal salts.
IM 51) IM 53)	Similar in composition to IM 50 but with higher molecular weights.
IM 68	Frother. C_{13} to C_{18} but also reported as cyclohexanol or n-octyl alcohols. This is probably due to confusion with IM 6-8.
IUM series	This series has been developed by the Institute Ural Mekhanobra. It consists of alkylamides synthesized from chlorohydrins of unsaturated fatty or resin acids and amino alcohols.
IUM-461	Has the structural formula $RCONHC_2H_4OH$ and a molecular weight of 340. R is an unsaturated fatty acid.
IUM-465	Has a similar structure but is formed from the resin acid and has a molecular weight of 400.
IUM-490	Has the structural formula $RCON(CH_2CH_2OH)_2$ and a molecular weight of 380. Like 461 it is formed from the unsaturated fatty acid.
KOS	Still-residues from the production of higher fatty alcohols.
KOK	Still-residues from the production of synthetic fatty acids.
M 60, M 72	Fatty-acid type collectors.
Nekals	Alkyl-aryl sulphonates.
NP 1	Sulphonated alkyl phenol.
NRV	Sodium salts of naphthenic acids.
ODTM	Saponified distilled Tall Oil.

OFA	Frother from Oxyethylated still residues of synthetic Fatty Acids.
Oksanol DL-12	Nonionic surfactant.
OP series	Condensation products of ethylene Oxide with alkyl Phenols.
OP 3) **OP 4)**	These are the products of reaction of 3 (4) moles ethylene oxide with a mixture of mono- and di-alkyl phenols having C_8 to C_{10} alkyl residues. They are reported in places to be non-ionic and may be used as emulsifying agents. The products may also be sulphated and the sodium salts are reported as OP 2, OP 3, and OP 4 having molecular weights of 200, 300 and 400 respectively.
OP 7) **OP 10)**	These have both been reported as flotation reagents having the approximate formula $R_2C_6H_3O\ (CH_2CH_2O)_9\ CH_2CH_2OH$ where R is an alkyl group such as C_8H_{17}.
OP 20	Probably this has a similar structure to OP 10 but a higher molecular weight. It also is utilized as an emulsifying agent.
OPSB	This is a frother formed as a reaction product of propylene oxide and Butanol. $C_4H_9\cdot(CH_2CHCH_3CHO)_nH$.
OPSM	A similar product to OPSB but produced from Methanol in place of butanol.
OR 100	A collector formed from oxidized recycle and consisting of synthetic aliphatic- and hydroxy-acids.
OS 20	An emulsifier used with oleic acid having the formula $C_{18}H_{37}O\ (CH_2CH_2O)_{10}\ CH_2CH_2O$.
PRV	Depressant containing sodium naphthenate.
PVPN	A polycationic flocculant based on poly 2-methyl 5-vinyl pyridine.
SFT 15	Frother consisting mainly of the methyl ester of α-terpineol.
Talams Zh **Talaset Zh** **Talleyl sulphate-2**	Three products synthesized from the fatty acid fraction of tall oil having the approximate respective formulae $RCONHCH_2SO_3Na$, $RCONHCH_2COONa$ and $ROSO_3Na$.

VS 2	Fatty-acid-type collector prepared from cotton-seed oil soap stock containing 68 per cent fatty acids.
VV 2	A non-toxic phenol-free frother. This is the residue from the production of tetrahydrofurfuryl alcohol and consists of a mixture of polyhydric alcohols and polymers. It also has weak flotation properties.
ZhKTM	Tall oil fatty acid mixture.

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