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THE DEVELOPMENT OF STRUCTURE IN WHIPPED CREAM

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Abstract

Interfacial changes occurring during the formation of whipped cream were followed using transmission and scanning electron microscopy. During the initial stages of whipping, air bubbles were stabilized by adsorbed β-casein and whey proteins with little involvement of fat globules. The adsorption of fat to air bubbles occurred when the globule membrane coalesced with the protein-air-water interface. As a result, fat was brought into direct contact with air but only rarely did it spread at the air-fat interface. The cross-linking of fat globules adsorbed to adjacent air bubbles by chains of coalesced globules established a stabilizing infrastructure in the foam. In the final whipped cream, the surface of each bubble was stabilized by variable amounts of adsorbed fat and by the original air-water interface of adsorbed proteins. Although these remnants of protein do not contribute to the mechanical properties of the foam, they betray the mechanism of bubble stabilization. A similar foam structure was also found in dairy and non-dairy aerosols examined by freeze fracturing. Modifying the protein composition of the aqueous phase before whipping may have important effects on the final foam because of the way this affects the composition of the air-water interface and, subsequently, the ease of fat adsorption to air bubbles.

Introduction

When cream is whipped, the oil-in-water emulsion is transformed into a three phase system in which incorporated air bubbles are held in a network of fat globules. From theoretical considerations and morphological evidence, an overall concept of how this structure develops during whipping has emerged from the work of a number of authors (Graf and Müller, 1965; Mulder and Walstra, 1974; Buchheim, 1978; Schmidt and van Hooydonk, 1980; Darling, 1982). This concept is very largely based on the original description given by Mulder and Walstra (1974) and can be summarised in the following way. When air is initially incorporated, high surface tension at the air-water interface results in the adsorption of fat globules and then of protein. Fat adsorption involves the partial loss of fat globule membrane and spreading of fat, especially if it is predominantly liquid, at the air-water interface. Since the system is highly dynamic, at least three types of change to the air bubble may then occur: coalescence, size reduction or collapse. Subsequent reduction of the surface area of the air-water interface of some bubbles encourages the formation of clumps, some of which are released from the interface either by collapse of the air bubble or as a result of shearing effects and are then available for adsorption to other air-water interfaces.

Morphological evidence of the events in the whipping process presented by Graf and Müller (1965) and by Schmidt and van Hooydonk (1980) suggests that when whipping is complete, air bubbles are completely surrounded by a continuous layer of fat derived from coalesced fat globules. Valuable as they are, such observations shed little light on the sequence of interfacial changes, some of which are predicted by the theoretical considerations outlined above, that lead to the formation of a stable foam. The objective of the present work was to examine these changes at the air-water and fat-water interfaces in dairy cream using both high resolution transmission electron microscopy and freeze fracturing methods in conjunction with scanning electron microscopy. Whilst it has been stated (e.g., Darling, 1982) that during whipping and aeration of cream, fat droplets interact with air bubbles whose air-water interface is devoid of adsorbed surfactant, more recent work on skimmed milk foams (Brooker, 1985)
strongly suggests that a protein interface containing whey proteins and, perhaps, β-casein, would be rapidly formed. Although protein adsorbed at the air-water interface is briefly mentioned by Mulder and Walstra (1974) in their mechanism for the stabilization of whipped cream, in no previously reported work has evidence been adduced to support the role of protein in this process.

### Materials and Methods

#### Whipped cream

Milk obtained from the Institute herd was pasteurized at 72°C for 15s and separated at 40°C using an Alfa Laval laboratory separator. The cream, whose fat content was adjusted to 38% (w/v) was held for 2h at 4°C and then whipped using the apparatus designed by Scurlock (1983), which was a modification of the device originally used by Mohr and Koenen (1953) and by de Vleeschauwer et al. (1961). It consisted of two wire beaters rotating at constant speed whose spindles were attached to a differential gearing mechanism and a potentiometer which allowed the load on the beaters to be constantly monitored as the viscosity of the cream changed. The load on the beaters was measured and plotted against time and the point at which there was no appreciable increase in the stiffness of the cream was taken as the end or whipping point. Overruns of 100-110% were routinely obtained.

Two proprietary brands of aerosol whipped creams were also studied using freezing methods in conjunction with scanning electron microscopy as described below. One of these was a UHT dairy cream (containing cream, sucrose, glycerol mono-stearate emulsifier and carrageenan stabilizer) with 400% overrun but with exceptionally poor stability, collapsing within 5min. The other was a non-dairy cream (glucose, fructose, hydrogenated vegetable oils, ethylmethylcellulose stabilizer, polyglycerol esters of fatty acids as emulsifier, salt, colouring and water) with a very high overrun but with very good stability, showing little sign of deterioration even after several hours.

#### Transmission electron microscopy (TEM)

Samples of cream at various stages of whipping were collected on loops (3mm diameter) of platinum wire and fixed according to the method given by Graf and Müller (1965). This involved treatment in formaldehyde vapour for 5min at 4°C and then in osmium tetroxide vapour for 3h at 4°C. The temperature was then slowly raised to 18°C and fixation allowed to continue for 5-6d to allow complete penetration of the osmium tetroxide and its reaction with the fat. In this fixation procedure, initial penetration of the aldehyde is rapid and allows protein structures to be stabilized sufficiently to resist the effects of volume changes in the bubbles when the temperature is subsequently raised to 18°C. The specimens, while still attached to the wire, were dehydrated by immersion in a graded series of acetone-water mixtures and 100% acetone. The foam was then removed from the loop and embedded in Araldite, Sections were cut on a Reichert OmU3 ultramicrotome, stained with lead citrate and examined in a Hitachi 600 electron microscope at an accelerating voltage of 100kV.

Changes in the appearance of the milk fat globule membrane (MFGM) during the whipping processes were also investigated using a different method of specimen preparation. Sufficient 25% glutaraldehyde was added to partially or completely whipped cream to give a final concentration of 3%. This led to the collapse of the foam but allowed high resolution study of the surface of fat globule clusters. After 1h, the mixture of cream and fixative was solidified by addition of an equal volume to molten 25% (w/v) agar and then cooling. The agar gel was chopped into small pieces with a razor blade and fixed for 2h by immersion in 1% osmium tetroxide buffered to pH 7.2 with 0.2M cacodylate-HCl. After dehydration in a graded series of acetone-water mixtures and 100% acetone, specimens were embedded in Araldite and examined further as described above.

#### Scanning electron microscopy (SEM)

Samples of partially or completely whipped cream were examined in a frozen state in a Philips 505 scanning electron microscope fitted with a Hexland freezing stage and cryo-transfer device. A small volume of whipped cream was placed on the end of a 2mm diameter copper rivet and another rivet was placed on top of it. Within 30s of collecting the sample, this assembly was plunged into nitrogen slush which had been prepared from liquid nitrogen by evacuation with a rotary pump. The two rivets with the entrapped cream were then attached to a specimen holder, placed in the preparation chamber under vacuum and one rivet dislodged in order to fracture the frozen cream. After flushing the chamber with dry argon, the fractured face of the cream was coated with gold using a sputtering head and then transferred to the freezing stage of the microscope for examination. In some cases however, the samples were etched by subliming some of the surface ice before coating with gold. This was done in a controlled way by observing the uncoated specimen in the microscope at low accelerating voltage (1-5kV) whilst raising the temperature of the sample by means of an in-built stage heater. Sublimation was performed at -80°C for a period of time which depended on the vacuum performance of the microscope and the depth of etching required. When this was completed and the sample had been cooled to liquid nitrogen temperature once more, it was transferred from the microscope to the preparation chamber and coated with gold before examination again in the microscope at higher accelerating voltages (10-30kV).

Polyacrylamide gel electrophoresis (PAGE)

In order to determine the composition of the air-water interface of the bubbles initially formed in whipped cream, a model system was used. Because the soluble proteins in the aqueous phase of cream are identical to those in milk plasma, interfacial material from milk plasma foams was used to provide compositional information on the same air-water interface of bubbles formed at the beginning of whipping in cream before fat adsorption begins. Interfacial material from collapsed milk plasma foams was prepared as described previously (Brooker, 1985). Qualitative gel electrophoresis was performed as described by Andrews.
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(1983). Separation gels of T=12.5%, C=4% were prepared by dissolving 12g acrylamide and 0.5g N,N'-methylenbisacrylamide (Bis) in 100 ml of pH 8.9 buffer (46g Tris + 4.0 ml concentrated HCl diluted to 1:1) and adding 30 µl N,N,N',N'-tetramethylenediamine and 40 mg ammonium persulphate immediately. A stacking gel of T=4.2%, C=5% was used (2g acrylamide + 0.1g Bis in 50 ml of pH 7.6 buffer made up of 7.5g Tris + 4.0 ml concentrated HCl diluted to 1:1) and 25 µl N,N,N',N'-tetramethylenediamine and 20 mg ammonium persulphate were used as polymerization catalysts. The apparatus buffer was Tris-glycine and gels were run at approximately 25V/cm for about 75-90 min. Staining was for 1h in 0.25% (w/v) Coomasie blue G250 in 50% methanol containing 12.5% trichloracetic acid. This was followed by washing for 10 min in 5% trichloracetic acid and destaining in 7% acetic acid.

Centrifuged pellets of interfacial material were dissolved by stirring in the separation gel buffer (pH 8.9) and then applied directly to the sample slots in the gel slab.

Results and Discussion

The conditioned cream was examined before whipping by TEM and was found to exhibit normal morphological characteristics, the surface of each globule consisting of a mixture of primary and secondary membranes (terminology of Wooding, 1971). This was best seen in conventionally fixed material for, after prolonged vapour fixation, there was a marked tendency for surface detail to be partially obscured by deposits of osmium-derived material. As a result of vapour fixation, the fat took on the same appearance as that recently described by Allan-Wojtas and Kalab (1984). It was very electron dense with lightly stained needle-like areas which, according to Allan-Wojtas and Kalab (1984), corresponds to crystals of saturated fat that have not reacted with the osmium tetroxide (Fig. 1). The prolonged cooling of the cream before use had caused some detachment of the primary MFGM from the globules, as might be expected from the work of Anderson et al. (1972).

In the results presented below, the events described at any given time after the start of whipping refer to cream whose end point was 80s for other cream samples whose whipping time was shorter or longer than this the same events took place on a proportional time scale.

Samples of cream retrieved only 10s after the start of whipping and examined by cryo-SEM, contained air bubbles whose internal surface was essentially smooth and showed limited evidence of fat globule adsorption to the air-water interface (Fig. 2). Because these air bubbles were not visible in the same material examined by TEM, it appears that they had burst before the stabilizing influence of the diffusing fixative had reached them. Bearing in mind that these bubbles were already 20-50s old before being frozen (see above), it is apparent that the incorporation of air into cream is not sufficient stimulus to cause fat globules to penetrate the air-water interface on a large scale. This behaviour is not that predicted by Mulder and Walstra (1974) for globules nearing an interface free of adsorbed surfactant, for the high spreading pressure of such a clean surface acting on the small area first presented by an approaching globule could be expected to rupture the MFGM and allow adsorption to occur. Recent work on skimmed milk and milk plasma foams (Brooker, 1985) has shown that the air-water interface of each bubble is a thin layer (4nm thick) of protein. In the present study, gel electrophoresis of interfacial material obtained from milk plasma foams showed that the interface contained β-casein as a major component with relatively smaller amounts of α-casein and other whey proteins (Fig. 3). Since the aqueous phase of cream is identical in composition to that of milk plasma, it is probable that the air bubbles initially incorporated into the cream are stabilized for a short time solely by the same interface of protein. However, since a discrete interface could not be resolved in the cryo-preserved material examined by SEM and the bubbles did not withstand the processing required by TEM, direct confirmation of its presence at the early stages is wanting. At this early stage, the dispersed fat globules appeared normal and showed little or no sign of coalescence or clustering.

The first direct evidence of an interfacial boundary layer at the surface of each bubble was found by TEM in cream that had been whipped for 20s. The air-water interface was identical to that previously seen in skimmed milk and milk plasma foams (Brooker, 1985), consisting of an electron dense layer, 4-5 nm thick, but to which individual fat globules had adsorbed (Fig. 4). Casein micelles attached to the air-water interface were seen but never in the numbers found in skimmed milk foams, probably because of their desorption (Brooker, 1985) before the diffusion of sufficient fixative could exert any effect. There was only occasional evidence of the spreading of liquid fat at the interface (Fig. 5) because, in most cases, globules retained their original shape. When adsorbed globules were closely packed, there was often fusion and displacement of the fat-water interface from the area of their mutual contact. When this coalescence occurred, the outline of the original globules was often retained because of remnants of the MFGM and/or by the persistence of the lightly stained peripheral fat crystals (Buchheim, 1970; Precht and Peters, 1981).

The salient morphological characteristics of the interaction between fat globules and the air-water interface were identical at all stages of the whipping process. In the case of adsorbed globules, the fat-water interface had coalesced with the air-water interface of the bubble in such a way that part of the fat was now in direct contact with the air and was slightly protruding into it (Fig. 6). This meant that the protein interface of the bubble was directly continuous with the fat-water interface of each of the adsorbed globules (Fig. 7). These results support the observations of Buchheim (1978) who showed that during fat adsorption, the MFGM in contact with the air bubble was removed and replaced by adsorbed surfactant. Since the surface tension of the fat-air interface was greater than that of the fat-water interface, the radius of curvature of the fat in
Conditioned and pasteurized cream showing needle-like fat crystals and the presence of initial MFGM (arrow). Micellar material has adsorbed to much of the globule surface. Bar = 1 μm.

Fig. 1

Air bubble in freeze-fractured cream which had been whipped for 10s. Very few globules (arrows) have penetrated the air-water interface of the bubble. Note that the fat globules show no sign of coalescence or clumping at this early stage. Cryo-SEM. Bar = 10 μm.

Fig. 2

Polyacrylamide gel electrophoresis of (a) milk plasma and (b) purified air-water interface of collapsed foam prepared from the same milk plasma. In the interfacial material note the presence of most of the whey proteins and the depletion of α-casein relative to the β-casein. β-cas = β-casein; αs1-cas = αs1-casein; α-la = α-lactalbumin; β-lg = β-lactoglobulin; A and B = variants of β-lactoglobulin.

Fig. 3

Cream whipped for 20s. Fat globules have started to adsorb to the air-water interface (i). Breaks in the interface demonstrate its fragility. a = air. Bar = 2 μm.

Fig. 4

A rare example of the spreading of fat (f) over the air-water interface (i). Note remnants of the MFGM (fm). a = air. Bar = 2 μm.
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Fig. 6. Cream whipped for 20s showing an adsorbed fat globule whose MFCM has coalesced with the air-water interface (i). Note the bulging of the fat globule into the air bubble and that the radius of curvature of the fat in direct contact with the air is noticeably greater than its water interface. Note the presence of material adsorbed to the MFCM (arrows). The air-water and fat-water interfaces are continuous. Bar = 1 μm.

Fig. 7. Cream whipped for 20s. An adsorbed fat globule (fg) showing continuity of the globule membrane (fm) with the air-water interface (i) (at arrows). A remnant of the fat globule membrane is evident at the fat-air interface (small arrow). a = air. Bar = 1 μm.

Fig. 8. An air bubble in cream 20s after start of whipping. The bubble surface is stabilized by adsorbed fat globules (fg) and by an air-water interface (i). Note the partial coalescence of the adsorbed globules. In the aqueous phase, many globules are normal in appearance but note globule clusters (small arrows) and coalescence (large arrows). The air-water interface of a collapsed bubble has casein micelles attached to it (bg). Bar = 2 μm.

Fig. 9. Coalesced fat globules in cream 50s after start of whipping. Outlines of the original globules are indicated by persistence of peripheral fat crystals (arrows). Note also remnants of free MFCM (fm). Bar = 2 μm.

Contact with the air was larger than that of the rest of the globule. This behaviour resembles that visualised by Mulder and Walstra (1974) for a fat globule penetrating a clean air-water interface devoid of adsorbed surfactant protein for which the spreading pressure was negative. The angle of contact of each fat globule with the air-water interface and the degree of fat protrusion into the bubbles was quite variable. These observations are consistent with previous accounts of whipped cream structure derived from freeze-fractured material in which the fat globules appeared to bulge into the lumen of the bubble (Buchheim, 1978; Schmidt and van Hooydonk, 1980; Darling, 1982).

In the present study, the rarity of globules that had spread over the bubble surface 20s into whipping can probably be attributed to their low content of liquid fat. It should be borne in mind,
however, that bubbles observed by TEM at this stage of whipping may represent only the most stable and that other bubbles, in which liquid fat has spread over the surface may have burst. Although single and aggregated fat globules covered much of the bubble surface, a significant amount of the original protein air-water interface frequently remained. This is clearly seen in Fig. 8.

The majority of fat globules were not associated with air bubbles and were not greatly changed from the starting material. However, in many cases the milk fat globules formed clusters in which the globule membranes of adjacent globules were in very close contact (Fig. 8) and it was not difficult to find evidence of globule coalescence (Fig. 8). The presence of free primary MFGM in the aqueous phase, identified by its characteristic unit membrane structure and associated electron dense material (Wooding, 1971), indicated that the globule surface consisted of a higher than usual proportion of secondary MFGM. It is entirely possible that modification to the globule surface was more radical than this and that damage to the native MFGM leads to the adsorption of micellar and soluble milk proteins in a manner reminiscent of homogenization. Such a process could not be conclusively demonstrated by electron microscopy in the present study but further investigations using labelled antisera to milk proteins will help clarify this point.

Other membranous fragments, only 4-5 nm thick, could not be positively identified but they resembled portions of secondary MFGM and could have arisen as a result of damage to the surface of fat globules. However, it should be remembered that some of this material, especially the frequently observed fragments with casein micelles attached (Fig. 8) might represent remnants of protein interfacial material derived from destabilised air bubbles.

During the remainder of whipping, there was a progressive increase both in the amount of free MFGM in the aqueous phase and in the number of coalescing fat globules (Fig. 9). After 50s, in what was a crucial step in the development of a stable foam, coalescence started to occur between globules already adsorbed at the air-water interface of adjacent bubbles (Fig. 10). This trend continued in such a way that at 60s and at the end of whipping, interfacial fat of neighbouring bubbles was connected by chains or by aggregates of coalesced globules. In completely whipped samples, the boundary of each of the many air bubbles did not significantly differ from that observed in the earliest stages. Although the spreading of fat at the bubble interface described by other workers (Mulder and Walstra, 1974; Buchheim, 1978; Schmidt and van Hooydonk, 1980) was observed, it did not predominate. Whilst the multiple coalescence of fat globules at the bubble surface has appeared to some authors (Buchheim, 1978; Schmidt and van Hooydonk, 1980) as liquid fat filling the spaces between individual solid fat globules, the persistence of their outlines categorically demonstrates that this is not so (Fig. 11). The boundary of each bubble in the final foam consisted not only of single and coalesced fat globules but also of a variable amount of the original protein air-water interface. An impression of the proportion of the surface stabilized by protein was best gained by examining the inside surface of bubbles in cryo-fractured preparations of foams. Thus, in Fig. 12, the continuous area between the convex faces of protruding fat globules represents the air-water interface. This feature has also been very clearly demonstrated in the micrographs presented by Buchheim (1978) and by Schmidt and van Hooydonk (1980).

In the aerosol foams, the structural elements at the bubble surface were identical to those
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found in whipped pasteurized creams; numerous, individually adsorbed fat globules were separated by areas of smooth air-water interface (Figs. 13 and 14). Consistent with the high overrun of both creams, the lamellae between air bubbles were very thin compared with those observed in the pasteurized creams. Although gross differences in the stability of the foams produced from dairy and non-dairy aerosols could not be explained in terms of interface structure, the appearance of the fat in the lamellae allowed the foams to be distinguished one from another. In the case of the stable non-dairy cream, the outlines of individual fat globules and clusters were clearly seen (Fig. 13) but in the unstable dairy foam, the fusion of fat was on a scale reminiscent of that seen in churning (Fig. 14).

Conclusions

The present study has shown that the stabilization of air bubbles in whipped cream involves the interaction of milk fat globules with the air-water interface composed principally of $\beta$-casein with much smaller amounts of other whey proteins. It is evident also that essentially similar interfacial events occur not only in foams made from pasteurized creams and UHT aerosol products but also from pasteurized and sterilized homogenized creams (Graf and Müller, 1965; Schmidt and van Hooydonk, 1980). Electron microscopy has shown that a crucial step in this process is the coalescence of the fat-water interface of each globule with the interfacial layer at the bubble surface. Only when this has occurred can the milk fat be considered to be permanently adsorbed and in direct contact with the air. In whipped pasteurized cream, the loss of primary and/or secondary MFGM during whipping may, by the subsequent adsorption of soluble whey proteins, lead to a surface modification of the globules which is essential for its fusion with the air-water interface. The finite time required for this to occur is consistent with the observation that after only 10s of whipping, virtually no fat globules are adsorbed to air bubbles. Modification of the fat globule surface has implications also for the ease with which globules coalesce and the stability of the resulting network of fat. The collapse of the network in the dairy aerosol examined in this study may reflect deficiencies not only in fat composition and/or crystallization but also in the properties of the fat-water interface. Compositional modifications of the fat-water and air-water interfaces may influence the readiness with which the two interfaces coalesce and, thereby, the ease with which fat adsorption takes place. Although the effect on whipping of changing the

Fig. 12 Freeze-fractured whipped cream examined by cryo-SEM. Numerous fat globules protrude into the lumen of a bubble. The smooth areas between globules represent air-water interface (arrows). Bar = 5 µm.

Fig. 13 Aerosol non-dairy "cream" showing that the interface structure of the bubbles is similar to that in Fig. 12. Note clearly outlined globules in the lamellae (arrows). Bar = 10 µm.

Fig. 14 Aerosol dairy cream showing the inside surface of air bubbles whose structure is similar to that in Fig. 12. Note the gross fusion of fat in the lamellae (arrow). Bar = 10 µm.
fat-water interface by homogenization (Graf and Müller, 1965) or by the use of emulsifiers (Mulder and Walstra, 1974) is well documented, the consequences of altering the air-water interface e.g. by heat denaturation of the milk proteins as in sterilization, require further investigation. The ability to isolate the air-water interface of protein foams as described in a previous report (Brooker, 1985) and to determine the protein composition of this material by PAGE as shown in the present study provides a means of relating interfacial composition to foam properties.

References


Discussion with Reviewers

D. Holcomb: Were the fixed foams blackened throughout, indicating complete penetration of the osmium tetroxide vapors?

Authors: Provided the loop was not loaded excessively with cream, penetration was always complete.

D. Holcomb: Were temperatures of the specimens monitored during sputter coating of fractured specimens for SEM observation? Was there any temperature rise during sputter coating or would you expect any such temperature rise?

Authors: Specimen temperature was monitored continuously during sputter coating and was found to rise 15°-20° C over a period of 4 min. Even so, the temperature never reached a point where sublimation of water or fat was significant.

M. Kalab: Why was fixation extended to 5-6 d? Was there any marked difference between micrographs of foams fixed for 1 d and micrographs of foams fixed for 6 d?

Authors: Prolonged exposure to osmium tetroxide vapour ensured complete penetration of the fixative and allowed sufficient reaction with the unsaturated fat to produce an electron dense matrix in globules throughout the foam. This was very important if details of fat adsorption were to be seen at the bubble surface.

In whipped cream fixed for 1 d on a 3 mm diameter loop, only a thin surface layer of the foam had a similar appearance to that seen throughout cream samples fixed for 6 d.

M. Kalab: Does the absence of fat globules in the air-water interface of foams whipped for only 10 s indicate that their adsorption would require more time and that the 10 s foams are not stable?

Authors: This observation shows that fat adsorption is not instantaneous as some authors have suggested. It is also consistent with the idea that modification of the native MFGM is necessary before widespread adsorption to bubbles can occur.

The bubbles in a 10 s foam are stable in the sense that they survive long enough for their transfer to the specimen holder and freezing but the foam does not have the same stability as a fully whipped cream.

W. Buchheim: On all TEM micrographs shown, a pronounced aggregation of milk protein particles (casein micelles) and also their interaction with the MFGM can be seen. Such an uneven distribution appears to be unlikely for the original whipped cream sample and might therefore represent an effect (i.e. artefact) due to the crosslinking reaction of the glutaraldehyde and/or the osmium tetroxide, Please comment.

Authors: You are quite right, we have taken cream samples at various stages in the whipping process and fixed them using conventional, short time
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exposures to glutaraldehyde and osmium tetroxide solutions. Although this treatment destroys the foam, it does give information on fat globule clusters and confirms that micelles are of 'normal' appearance with no aggregates or association with fat globules.

D. Carpenter: In Fig. 8, if the fat globules coalesce, wouldn't there be less of the original MFGM needed to stabilize the fat i.e. the total surface area is reduced?

Authors: Yes. We have evidence from work on the coalescence of fat globules in cream which suggests that the excess MFGM that results from this phenomenon appears as folds of membrane on the globule surface. This material is shed into the aqueous phase. The shedding process is evidently very rapid because even in cream where coalescence is widespread, it is difficult to find fat globules with their folds of membrane intact. We hope to report on this elsewhere very shortly.

D. Carpenter: It appears that the bridged globules are very important to the mechanical stabilization of the air cells and that the membrane is secondary. Is this correct?

Authors: Yes. The air-water interface is important in stabilizing bubbles until fat adsorption begins. In the final foam, the interface probably contributes very little indeed to the mechanical stability of the air cells. The important point we are trying to make is that the composition and properties of the air-water interface allow adsorption of fat globules to take place. Manipulating interface composition by changing the composition of the aqueous phase will probably have an effect on fat adsorption and therefore the macroscopic properties of the foam.