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Notes on Crystallites.

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THE work of the late Hermann Vogelsang, and the subsequent researches of O. Lehmann and other observers, have done much to show that a careful study of the rudimentary forms of crystallisation may prove as valuable to the mineralogist as that of embryology has already been to the comparative anatomist.

It is, indeed, difficult to form any clear conception of the manner in which a crystallite originated, nor can we go further back in the history of its development than a stage in which a number of atoms have been grouped in an arrangement about which there is yet no certainty, thus forming molecules grouped in some manner about which we are equally uncertain. We can but imagine that there is some inherent property in molecules which causes them, under given conditions, to group themselves in an orderly manner and to assume a form which may, when more fully developed, be referred to one of the recognised crystallographic systems.

Vogelsang was the first to indicate that the globulite is the most rudimentary form, revealed as yet by the help of the microscope, from which crystalline bodies become developed.

The following extract, translated from Rosenbusch's *Mikroskopische Physiographie*,[1] may serve as an appropriate preface to the suggestions in this paper.

"Vogelsang, who lays stress upon the symmetrical polyhedral form as the principal means for acquiring an understanding of crystals, recognises the development of crystallites and that of crystals as two different methods of the process of crystallisation, which are united through gradual transition. Whether the one or the other event will take place in a solution is, according to his idea, dependent upon the relation between the molecular resisting-powers in the solution and the molecular movements within the globulites. The form of the globulite is, however, according to him, the chief condition which determines whether a crystallite or a crystal will result from it. Between the two an almost infinite number of growth-forms occur, interwoven-forms (*gestrickte Formen*), crystal-skeletons ('*Krystalskelette*'), often many-branched, in which the closed form of the true crystal is lacking, in which the globulite is no longer recognisable as such, and in which, when symmetrical relations permit it, double refraction is exhibited.

"In the theoretical discussion, with which Vogelsang accompanies his observations, he does not attempt any special explanation of the formation of the globulites, and he refers the movements and the arrangement of the developed globulites, as well as their transformation into integral parts of a true crystal, to a molecular movement (crystallisation-power) inherent in them, which enables them to attract one another and group themselves regularly."

The globulites, formed in Vogelsang's experiments with sulphur dissolved in bisulphide of carbon and Canada balsam, were supersaturated drops of the solution which, on parting with their solvent, became solid bodies, minute, transparent, isotropic pellets of sulphur.

It is customary to regard globulites as balls or spheres, but, when we consider how diminutive they are and how small they appear, even when magnified over 1,000 diameters, it seems quite probable that a globulite has not in all cases a perfectly spherical form, but may sometimes be an ellipsoid. The difference between a sphere and an ellipsoid of such small dimensions would barely be appreciable, even under very high magnifying

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[1] 2nd Ed. Vol. I, p. 28.

powers, and it does not, therefore, seem unreasonable to suppose that what we term globulites may include ellipsoids of rotation and triaxial ellipsoids as well as spheres.

Petrographical literature has already made us familiar with these minute bodies, individually known as globulites (Fig. 1), collectively as margarites (Fig. 2), longulites (Fig. 4), &c. In addition to these a vast number of other microscopic bodies have been described and figured, but up to the present time no distinctive names have been given to them. At the risk, therefore, of encumbering petrography with new terms I venture to suggest some of the names given in the annexed table. It would, indeed, be next to impossible for me to explain what follows without recourse to such terms. The names already in use are underlined.

This table may serve as a provisional but very crude classification of crystallites, in which four groups or stages are recognised. These may be regarded as shading off one into the other, as there are no sharp lines of demarcation between them.

I. PRIMITIVE STAGE.

Globulite.

Margarite. Clavalite. *Longulite.* Spiculite.

Bacillite. (*Belonite.*)

II. SPHERULITIC STAGE.

Cumulite.

Spherulite. *Globosphærite.*

Axiolite.

Scopulitic Spherulite. *Trichite.*

III. SETULATE STAGE.

Scopulite.

IV. CHIASMOLITIC STAGE.

Arculite. Furculite.

$\frac{1}{2}$ Arculite. Biconcave Rotulite.

$\frac{1}{4}$ Arculite. Crenulite.

The first group or stage includes globulites, and those elongated forms which result from the coalescence, partial or complete, of several, sometimes of many globulites. These forms are too well known to need any description. The name clavalite is here given to club-ended longulites (Fig. 3), or dumb-bell shaped bodies, the term longulite being here restricted to cylindrical rods with rounded ends and of uniform dimensions from end to end of the cylinder. The bodies to which the name bacillite is given are of much greater size, and apparently consist of a number of longulites massed together with their longest axes parallel (Fig. 6). The term is convenient as indicating a rod-like body which does not present any recognisable crystallographic faces. The cumulite (Fig. 29) might be placed in this stage, but since these bodies appear at times to pass into globosphærites, they may be regarded as forming a connecting link between Stages I and II. They are here placed in the latter.

In Stage II. the cumulite (Fig. 29), or irregular aggregate of globulites, may, by accession of fresh globulites, ultimately form a spherical body known as a globosphærite (Fig. 30). Generally, however, spherulites have a radiating fibrous structure (Fig. 26), the fibres or minute crystalline rods diverging from a point or from several points situated at or about the centre of the spherulite. The rods may be either straight and single or they may split up into delicate branches. The surfaces of spherulites are sometimes smooth, at others rough, while occasionally their irregularity of surface is so great that their sections present roughly-jagged or toothed boundaries (Fig. 27), and in some cases, where the rock is almost wholly composed of them, they meet in polygonal boundaries. In these spherulites, with a radiating fibrous structure, we may assume that the separate fibres or rods have been formed by the linear arrangement of globulites, and in this respect they differ from those spherulites in which the globulites do not appear to have any definite arrangement, as in the globosphærites already mentioned. The elongated bodies known as axiolites possess the radial structure of a spherulite only to a limited extent, and that merely at the extremities of the axiolite (Fig. 25). Throughout the remainder of the body the fibres are radially disposed about a central axis, so that they lie at right angles to the roughly cylindrical surface of the axiolite. In general appearance they somewhat resemble spherulites which have been drawn or squeezed out of shape.

If we conceive the equatorial constriction of a plastic spherulite with a radiating fibrous structure, we can imagine that, according to the extent of the constriction, we should compress the fibres lying at right angles to the ligature and thus drive the remaining fibres into a sheaf-like form. By using a comparatively broad ligature we should form a rod, the length of which would be approximately proportional to the breadth of the ligature. The fibres passing from the ends of this rod would diverge around the poles of the compressed sphere and would sweep in curves towards the zone of constriction. This structure is not uncommon in some spherulites. Those shown in Figs. 23 and 24, occurring in a spherulitic lava from Mokua Weo Weo, in the Sandwich Islands, are good examples.

This kind of spherulite forms a connecting link between Stages II. and III. The trichites (Fig. 28), which have been provisionally placed in the same group with the spherulitic forms, may result either from the grouping of margarites about a common centre, or from the abnormal growth, as O. Lehmann has shown, of fresh material upon the terminations of crystals, so that they pass beyond the halo of crystallisation into the supersaturated mother liquor or magma, in which the currents bring such a plentiful supply of fresh material that the thin needle or thread increases very rapidly in length, while the impoverished solution streaming down its sides affords no material for increasing the breadth of the filament, the curvature of which he considers to be due to the action of currents.

Bearing the scopulitic-spherulite (Fig. 23) in mind, let us next turn our attention to the third or Setulate Stage, in which certain bodies occur which I have ventured to name scopulites in allusion to their brush-like character. In structure they appear to differ in no essential respect from the scopulitic spherulites, except that we can see little in them which suggests any relation to spherulites. This is, however, merely due to the length of the rod which carries the two brushes or plumes (Figs. 8 and 9), and if we wish to compare the very variable separation of the brushes, and consequently the variable lengths of the rods which carry them, we have only to examine a section of the well-known pitchstone of Corriegills, in Arran. Here we may see these scopulites in abundance; some with the brushes separated by long rods, others with the shortest possible stems. They frequently occur fringing the long spicular crystallites and spike-like rods of hornblende with their greenish tufts, and cause them to resemble the fronds of ferns, as in Fig. 10.[1] Scopulitic structure may also be seen in the hornblende of certain phonolites, hornblende schists, &c., the prisms splitting up at the ends into divergent fibres, as in Fig. 7.

Keeping this last or worn-out paint-brush type of scopulite before us, we pass on to the fourth or Chiasmolitic Stage. Here we have two forms of very common occurence in vitreous rocks, slags, &c., which I have termed arculites and furculites (Figs. 11 and 14) on account of structural peculiarities which respectively characterise them.[2] Of the two the arculite is the more closely allied to the scopulite. The leading characteristic of the arculite is the presence of four main ribs, like bows set back to back so that their concavities are facing outwards (Fig. 11). This structure may be

[1] This is a diagrammatic figure. These growths are frequently irregular. They sometimes occur as mere arborescent growths, as in Fig. 35, and are then barely recognisable as scopulites.

[2] Forms of this kind are described by Krukenberg as chiasmolites. "Mikrographia der Glasbasalte von Hawaii." Tübingen, 1877.

seen in crystallites or crystal skeletons of felspar, olivine, &c., met with in certain volcanic rocks, usually vitreous. The structure, however, is not confined to crystallites, for distinct evidence of it may often be seen in well-formed crystals, as in the felspars of some trachytes, in which the skeleton structure, although its interstices are now filled in, is still clearly apparent. The four bow-like main ribs of the arculite are sometimes so close together that their convex sides are in actual contact, at others they are more or or less widely separated.

From their extremities towards the middle of each bow delicate comb-like growths are developed, those proceeding from the one bow following the direction of curvature of the adjacent bow. They are, as a rule, but slightly developed towards the middle of each bow. In section two bows or main ribs only appear, but in reality four are present in each fully-developed arculite.[1] Sometimes a small crystal form may be seen to occupy a position midway between the bows, and it not unfrequently happens that the bows are small or dwarfed, forming mere horns on the solid angles of the diminutive crystal form.

The arculites are very closely related to the furculites, which I have so named on account of their fork-like structure.[2] In the latter there appears to be a central main stem, which forks at its extremities into straight prongs which, as a rule, enclose tolerably wide angles (Fig. 14). At each extremity of the main stem there are four of these prongs. Two of them only are seen at each end of the main stem in microscopic section, when the plane of section is parallel to the main stem.

Pectinate growths proceed from each prong, those of the one prong apparently following the direction of the adjacent prong. The general structure so much resembles that of the arculite, that there is evidently a close relationship between these two forms.

In a furculite occurring in a section of Mexican obsidian there is a repeated tendency to develop scopulitic structure, the directions of the scopulitic fibres approximating to those of the pectinate growths of the furculite (Fig. 32).

The lath-shaped microlites so frequently seen in microscopic sections of volcanic rocks also seem, at times, to be in some respects related to furculites, especially those which, owing to an excessive growth from their solid angles, have developed projections of various kinds, sometimes

[1] In hemihedral forms, however, only two main ribs would be present.

[2] The forms which I have here termed arculites and furculites were named chiasmolites by Krukenberg, and I have in consequence applied the name to the group or stage in which they occur.

swallow-tailed in form (Figs. 17 and 20), at others stepped or crenulated (Figs. 18 and 19). I have provisionally included them all in the preceding tabular classification under the name crenulites.

Allied to the furculites and arculites, but especially to the latter, are some peculiar forms which at first sight appear to belong to a separate group. It would seem, however, that they are hemihedral and tetartohedral forms derived from the arculite.

That shown in Fig. 13 appears to be derived from the arculite by the development of alternate pairs of octants, while that in Fig. 12 seems to result from the development of two octants (2 and 8, 1 and 7, 3 and 5, or 4 and 6), one above, and the opposite one below the diametral plane.[1]

The forms which we have now been considering comprise, I believe, the chief types upon which crystallites are built up. Doubtless there are others which I have never seen, or which may have been overlooked. There is, however, one peculiar form which I think is worth description.

This very remarkable example of discoidal crystallisation is afforded by the partial devitrification of a green glass from the St. Helen's Works, occurring in a large series of specimens forwarded to me by Mr. Douglas Herman for examination. This specimen, which is of a clear deep green colour, contains a great number of white, biconcave, circular discs, some of which occur singly (Fig. 15a), while others form interpenetrating groups, one disc lying at right angles to the other with the margin of the one passing through the centre of the other (Fig. 16). At other times they interpenetrate at an angle less than 90°, but as they are more or less deeply embedded in the glass, the angles at which they intersect cannot readily be measured. These bodies may clearly be seen by unassisted vision or by the help of a pocket-lens.

A large proportion of them appear massed together in a confused manner like heaps of diminutive coins. The concave surfaces of individuals occasionally meet or intersect, so that a small speck of green glass may be seen to occupy the centre of the disc. Where the specimen is broken and the fracture passes through one of these bodies, at right angles to its circular section, as in Fig. 15b, its biconcave nature is clearly revealed. For such a body I propose the name biconcave-rotulite.[2] Whether these rotulites bear any relation to spherulites has yet to

[1] The curved stems of these forms appear at times to consist of longulites, so grouped that they overlap like tiles on a roof (Fig. 31). See Explanation of Plate.

[2] When this paper was read the term biconcave-discolite was employed. Since, however, Prof. Judd objected to the term on the ground that it was already used to designate certain microscopic bodies occurring in calcareous deep-sea deposits, the name rotulite has been substituted.

be determined, but in structure, at all events, they are quite different. In the biconcave-rotulite any section passing through its centre and at right angles to its circular section shows a structure which, in some cases, is precisely that of an arculite, in others that of a furculite. It would seem, indeed, that this form would result from the revolution of an arculite or of a furculite about an axis normal to the main stem.

We may assume that one section of the rotulite is circular, judging from the appearances which these bodies generally present in the hand-specimen. In a section cut from it, however, there are some rather small transparent sections which are decidedly hexagons, and on measuring the angle at which some of the more delicate crystalline growths, lying in the interior of the hexagon, intersect, it was found to be 60°. Such an hexagonal section may be derived from the interpenetration of three rotulites of equal dimensions at 60° to one another.

In the forms of the Chiasmolitic Stage which have just been described, the relation of the arculites, furculites, and rotulites appears to be a very close one. If now we compare the various forms of crenulites with those of arculites and furculites, we see in the boundaries of the former a certain approximation to the forms of the latter. Compare, for instance, Fig. 17 with Fig. 11, and Figs. 19, 20, and 21 with 14, and we can picture in the crenulites the partial or complete filling in of the skeleton-forms of arculites and furculites. In connexion with this it may be interesting to note that if a glass solid of the form which would result from the filling in of a furculite, such as that represented in Fig. 14, be devitrified, the lines in which the arrest-planes[1] meet would correspond in direction with the main stem and prongs of the furculite if the rate of the growth in the latter were equal in all directions, and a section through such a devitrified prism would resemble that shown in Fig. 34. In this instance, however, we have the lines, formed by the meeting of the divisional planes in the solid, resulting from the development of crystalline rods or bundles of crystalline rods, which, originating on the limiting surface of a polyhedral form, pass *inwards* until those proceeding from one surface arrest those proceeding from another surface, while in the filling in of a furculite we have growths which take place *outwards* from pre-existing lines. The one process is, in fact, the reverse of the other.

A few of the figures given in the plate have not yet been alluded to, but have been inserted as illustrative of certain structures already noticed. The figures are briefly described in the explanation of the plate.

1 "Anniversary Address, Geological Society." By Prof. T. G. Bonney, 1885. *Proc. Royal Soc.* Vol. 39, p. 90. Herman and Rutley, 1885.

In conclusion, the chief points suggested in this paper may be summarised as follows :—

Stage I.—The Primitive Stage comprises those bodies only which are either individual globulites, aggregates of globulites, forming elongated, moniliform, cylindrical or fusiform bodies, or bacillites resulting from the parallel grouping of such elongated forms. In no case has the globulitic element assumed a polyhedral form in this stage.

Stage II.—The Spherulitic Stage results from the grouping of members of the primitive stage into bodies which are usually more or less spherical, and sometimes with, at other times without, a radial arrangement. Occasionally these bodies show considerable departure from the spherical form, such differences being due to the same causes which determine the idiomorphic and allotriomorphic characters of crystals.

Stage III.—The Setulate is closely related to the preceding stage, the connecting link being the scopulitic spherulite. No pectinate growths are present in the scopulites, and they differ from one another only in the development and curvature of their constituent fibres, and in the length of rod by which their brushes are separated.

Stage IV.—The Sagittal Stage is related to the preceding, but less closely than at first sight appears. The fibres or rods of the scopulites do not bear any apparent relation to the curved main ribs of the arculites, or to the forked main ribs of the furculites, and consequently cannot be regarded as indicating definite arrest-planes. In the forms of the sagittal stage, which are essentially skeleton crystallites or crystals, there is a main skeleton which seems to correspond with the boundaries of the arrest-planes seen in similar glass solids when devitrified, these arrest-planes bearing a definite relation to the symmetry of the body in which they occur. Pectinate growths proceed from the limbs of the main skeletons of sagittal crystallites. No such growths are met with in the setulate stage.

By so shortening the central rod of the main skeleton of a furculite that the points from which the upper and lower series of forks originate are brought together, the central rod becomes abolished. If now the alternate forks of the upper series be brought together and also the alternate forks of the lower series, so that they coincide or unite to form a single rod, the skeleton will then become that of a pyramid or other closed simple form. Conversely, by separating the skeleton of a pyramid into forks, and by the development of a central rod separating the upper series of forks from the lower series, the skeleton of the corresponding prism is formed.

It seems probable, therefore, that the sagittal forms represent the framework of all polyhedral crystallites or skeleton crystals. Much remains to be done in working out the relations of the forms.

How far the views expressed in the foregoing very imperfect sketch may be borne out by known facts or by further observations, is a question about which there is probably some doubt, and it may be that I have speculated far too freely and generalised to an unwarrantable extent upon the limited material at my disposal.

Explanation of Plate.

Typical Forms of Crystallites.

Primitive Stage.

1. Globulite. 2. Margarite. 3. Clavalite.
4. Longulite. 5. Spiculite. 6. Bacillite.

Setulate Stage.

7, 8, 9. Scopulites. 10. Scopulitic growths occurring in Pitchstone, Corriegills, Arran.

Chiasmolitic Stage.

11. Arculite. 12. ¼ Arculite. 13. ½ Arculite. 14. Furculite. 15a. Biconcave-rotulite, St. Helen's Glass-works. 15b. Section of same, showing arculite structure. These bodies sometimes possess the structure of furculites.

16. Biconcave-rotulites interpenetrating apparently at right angles. St. Helen's Glass-works. 17, 18, 19, 20. Crenulites.

21. Same form as No. 20, but with the re-entering angles filled in.

22. Lath-shaped microlite.

Spherulitic Stage.

23. Scopulitic Spherulite.

24. Ditto, showing irregular boundary. Lava of Mokua Weo Weo, Sandwich Islands.

25. Axiolite, 26. Spherulite. 27. Spherulite with jagged boundary. Felsitic Lava, Glyder-Fawr, North Wales. 28. Trichite. 29. Cumulite. 30. Globosphærite.

Supplementary Illustrations.

31. Portion of slender undulate rod, the concave aspects of which show an imbricate arrangement of longulites. The orientation of the latter is the same on either side of the central or nodal point, but in the surrounding glass detached or barely adherent longulites may be seen; those on one side of the rod differing in their orientation from those on the other side. On focussing $\frac{1}{3500}$ inch lower, two other fringes of barely adherent longulites are brought into view, but they are orientated in directions the reverse of those seen at the higher focus. These fringes extend along the

curved rod for about $\frac{1}{5}$th of its entire length. Pitchstone, Corriegills, Arran. × 780 linear.

32. Portion of crystallite showing furculitic structure (F); passing into scopulitic structures (S). Obsidian, Mexico. × between 150 and 200 diameters.

33. Crystal of sanidine, twinned on Carlsbad type and showing divisional markings suggestive of furculitic structure. Trachyte, Berkum, near Bonn, Rhine. × cir. 80 diameters.

34. Diagrammatic vertical section of a square prism of glass, completely devitrified and showing the traces of arrest-planes joined by a central line of arrest which coincides with the principal axis of the prism. The resemblance of the divisional lines in this section to those observed in crystallites and crystals which show a furculitic structure is at once seen on comparing this figure with Figs. 32 and 33.

35. Irregular arborescent growths upon portion of a slender rod of hornblende in pitchstone, Corriegills, Arran. Examples are seen in this rock in which the direction of curvature of these growths upon one side of the rod is the reverse of that seen upon the opposite side. Such growths may be regarded as imperfectly developed scopulites, which, growing at close intervals and springing obliquely from their points of attachment, are unable to develop the perfect scopulitic form.

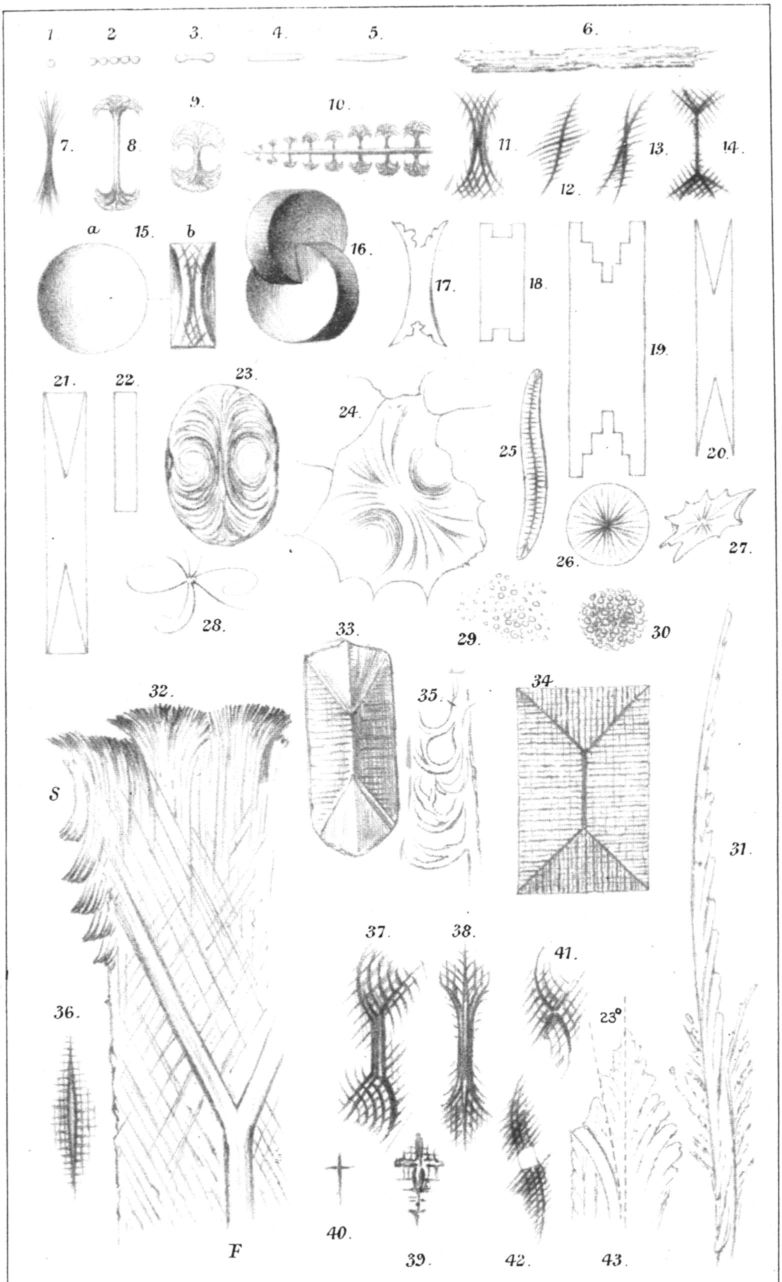
36, 37, 38, 39. Skeleton crystals in basalt-glass, Kilauca, Sandwich Islands. Three different sections, apparently of the same crystal form, are shown in Figs. 37, 38, and 39. Fig. 39 is probably a section approximately at right angles to the vertical axis.

40. Section similar to Fig. 39 (embryonic form). Basalt-glass, Kilauea. × 250 linear.

41. Skeleton crystal, Basalt-glass, Kilauea. × cir. 250 linear. Such a form might apparently be derived from that shown in Fig. 37 by shortening the central rod of the latter.

42. Skeleton crystal, basalt-glass, Kilauca. × cir. 250 linear, with small closed crystal-form developed in the centre.

43. Portion of crystal of sucrate of lime, showing arculite structure. The direction of maximum extinction makes an angle of 23° with the vertical axis.



Frank Rutley del.