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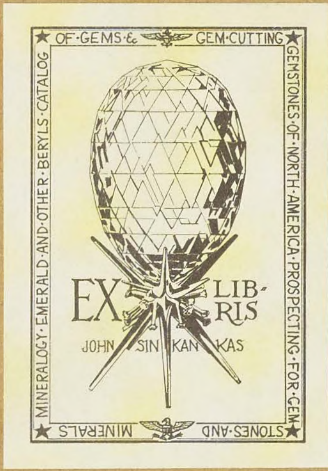
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STRUCTURE OF AGATES
BY
PROFESSOR M.F. HEDDLE.

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No. XII.—ON THE STRUCTURE OF AGATES. By the late M. FORSTER-HEDDLE, M.D., Emeritus-Professor of Chemistry in the University of St. Andrews, Hon. Member. With Thirty Illustrations from Drawings by the Author.

CHALCEDONIC and zeolitic druses represent the former vapour vesicles of igneous rocks, which vesicles have, after partial alteration of the latter, been more or less completely filled by the deposition of decomposition-products of the several minerals which compose the rocks. These decomposition-products have been carried in solution—probably in water—into the vesicles by endosmose—as into shut cavities. Within the vesicles they have been deposited in successive layers, through which layers endosmose continued to act. After the deposition or coagulation of the material forming the layers, the solvent liquid was forced out of the cavity through one or through many openings by the entrance of a new quantity of strong solution, according to the ordinary law of endosmose. These openings may be called *tubes of escape*.

When the druse has been more or less completely filled by the various modifications of silica—hydrated or anhydrous—it is termed an agate, but no absolute line can be drawn to separate such from a *zeolitic* cavity, as one cavity may contain both siliceous layers and zeolites, and that in varying order of superposition. Neither can it be definitely stated which ingredients of

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the rock by its decomposition determines the formation of either; but this distinction has to be pointed out in the formation or filling-up of such druses, namely, that there is *a perfectly definite order* in the successive deposition of the various zeolitic minerals which fill drusy cavities, while there is no definite order whatsoever in the deposition of the various forms of silica, the layers of which form an agate.

It is the formation of this last which is here considered.

AGATES: NORMAL STRUCTURE.

FORM.

The form of the vapour-vesicle is determined by the amount of fluidity or of viscosity of the flow through which it is ascending; and also by the state of the flow—whether of motion or of rest. If it had little or no motion and great fluidity, the vesicle, especially if it be small, is *round*. When the viscosity of the lava was so great that the vesicles rose with difficulty while the flow still continued, the vesicles have been drawn out into more or less of a *rod-shaped* form, and often lie horizontally—the more rounded extremity pointing in the direction of the flow. If there has been little motion and considerable fluidity the vesicle is *pear-* or *balloon-shaped*. If some motion and considerable fluidity it is *axe-shaped* (fig. 1). If rapid motion and considerable fluidity it is *lanceolate*. When very large there is frequently an elevation in the centre of the floor, as in a *wine bottle*. Agates with a flat side are almost invariably *onyx-agates* (fig. 2). The flattening may have resulted from the matrix concreting and solidifying at a uniform distance from the underlying cooling surface: (as this surface has been probably somewhat sloping, the onyx banding, which is invariably horizontal, does not always absolutely accord with the flat surface). When, subsequent to solidification, a rent has been formed in the rock, the rent may, when not opening to the surface, become coated on both sides with chalcedony, and so form a *vein-agate*.

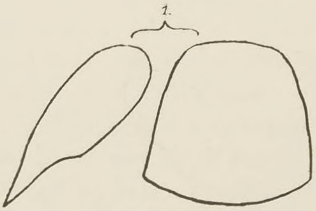

Fig. 1.—Axe-shaped Agate in two positions.

THE LAYERS.

The substances which form the layers or bands of agate are—the skin, chalcedony, carnelian, cacholong, girasol opal, wax opal,—all of these are colloids—and hydrated silica; quartz, amethyst, cairngorm,—all of which are crystalline—and anhydrous silica. Jasper rarely occurs.

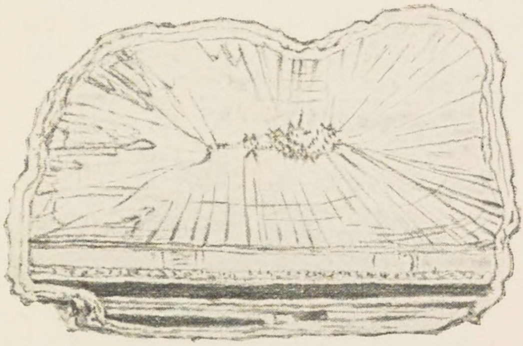

Fig. 2.—Onyx-Agate: Onyx parallel to flat side, Druse filled with Quartz.

These several substances may be deposited in any order from without inwards (figs. 3 and 4)—the hydrated varieties being usually the earlier deposited. Clear chalcedony usually forms the outer

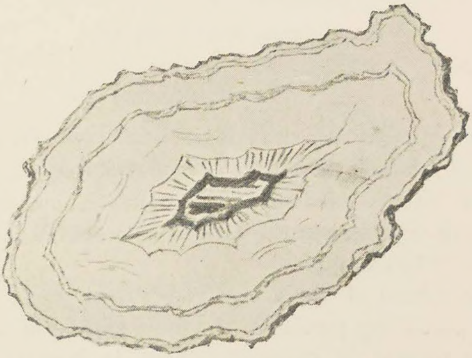

Fig. 3.—Varying Order of Deposition.

layer—after the skin; this is succeeded by milky chalcedony, or by cacholong. Amethyst, quartz, or carnelian, usually form the centre. When quartz or amethyst is in quantity, and is the last deposited layer, an unfilled central cavity often remains. When carnelian fills the centre it is frequently rent. At some localities girasol or milk-opal forms the outer zone.

The regular concentric deposition of the layers of an agate is due to a considerable and uniform amount of adhesion between the surface of each layer and that of the layer previously deposited. When that adhesion is weak the layer may be somewhat thickened towards the lower part of the cavity,—gravitation in this case operating upon the only partially solidified chalcedony.

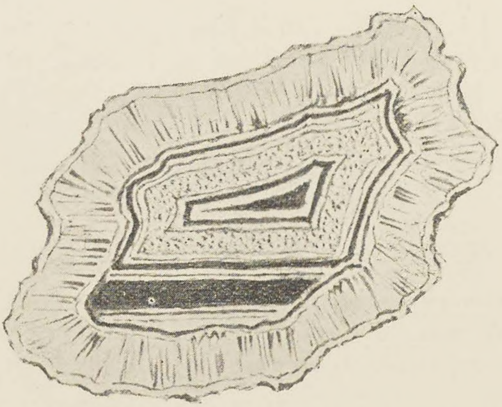

Fig. 4.—Varying Order of Deposition.

The Skin.

The first or outer-deposited layer in the vesicle results from the decomposition of the augite of the rock matrix. This layer consists of either celadonite, chlorophæite, or delessite. If labradorite or nepheline in the rock be also altered it may consist of natrolite or heulandite.

The first three of these materials which form the "skin" invariably coat every portion of the inner surface of the cavity.

If it be present in *unusual* amount it appears in threads pendulous from the upper part towards the lower part of the cavity (fig. 5). Such threads, upon the after-injection of siliceous solutions, determine the formation, and form the centre of so-called *stalactites*.

When it is in *large* amount it is deposited as an interlacing net-work of fibres. These, upon being sheathed by the ingress of siliceous solutions, determine the formation of *moss-agates* (fig. 6).

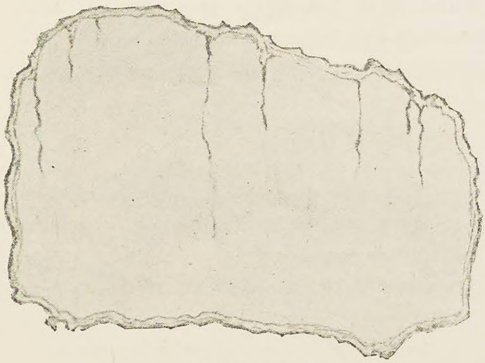

Fig. 5.—Celadonite Stalactites.

Stalactitic Agates.

The first layer or layers of chalcedony invariably coat every part of the surface of the celadonite or skin. In an ordinarily formed agate the surface of these layers is smooth; but, where the celadonite invested a rough cavity, the chalcedony is slightly mammillated.

In such agates as contain pendulous threads of celadonite, these are coated by the chalcedony to a thickness equal to that on the sides of the cavity; so that pendulous processes of chalcedony, simulating stalactites in appearance and form, result.

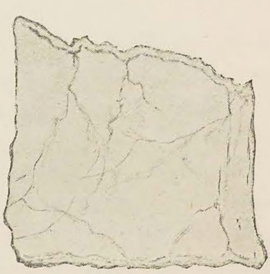

Fig. 6.—Interlacing Celadonite, the Framework.

Should the process of filling of the cavity be completed by any new arrangement of parts, the stalactites come to be imbedded in the substance of these new arrangements. Any difference in the manner in which they are so imbedded alters much the appearance of the agate (figs. 7, 8, and 9).

Moss Agates.

In manner identical with that which obtains in the formation of stalactitic agates are *moss agates* formed. These may exist as an open network of mutually interlacing tortuous strings, or the continued filling up of the cavity may unite all into a solid mass. In some localities the filaments of moss agates have a dendritic or tufted arrangement; they are then generally brown or yellow in colour.

Structure.

Like malachite, göthite, hæmatite, and all substances deposited from solution upon uneven surfaces, the chalcedonic matter of agates has a double structure, the second of which lies more or less at right angles to the bounding surfaces of the first. There is a surface-enfolding deposition in layers, which successively assumes more and more of a *mammillated* appearance; and a divergent or *radiating acicular* structure, which lies more or less at right angles to the first. This incorporated dual structure is nearly equally manifest when the agate is cut in a direction which cross-sections the layers.

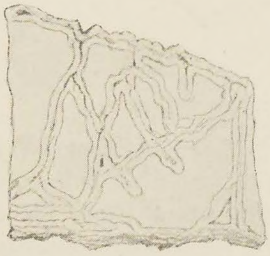

Fig. 7.—First Coating of Chalcedony on Celadonite Filaments.

As the material which forms the acicular structure is much less soluble in alkalies than is the general substance of the chalcedony, and as it is anisotropic, it is probably of the nature of *tridymite*—the general mass being colloidal, and true *chalcedony*.

The thickness of the layers of this latter increases with the amount of impurity in each layer.

So long as the material deposited is of the same nature, the adhesion of the several layers is perfect, and the most facile fracture is along the fibres of the divergent spiculæ.

At the margin of any alteration of material there is much less, sometimes little or no, adhesion, and but a slight shock is sufficient to detach the layers from each other.

Cacholong Agate.

The substance cacholong (Mongolian, kaschtschilon—*beautiful stone*) is usually classed with the opals, and is of a somewhat mixed composition—one which indicates a small admixture of a zeolite with opal.

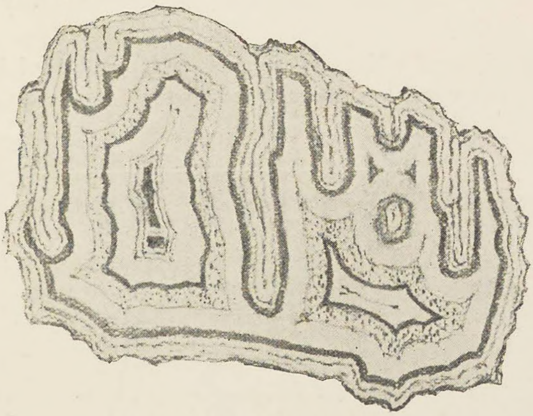

Fig. 8.—Varieties of Agate Building.

The cacholong which forms the white band of Scottish agates consists, however, in far the greater number of cases, of a

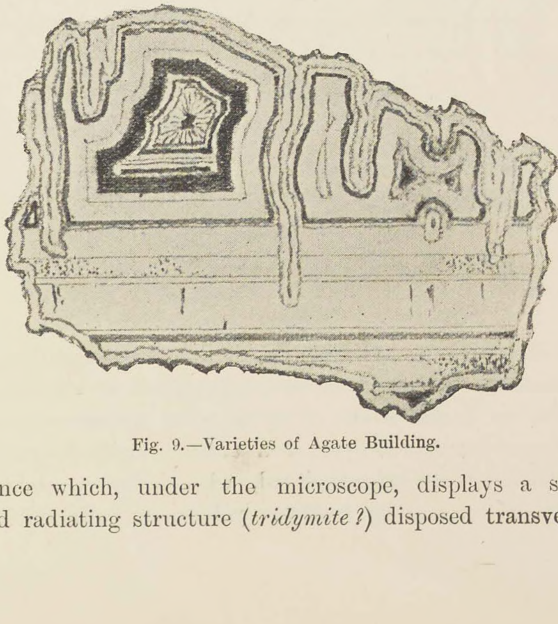

Fig. 9.—Varieties of Agate Building.

substance which, under the microscope, displays a strongly-marked radiating structure (*tridymite ?*) disposed transversely to the bands, and penetrating a magma of highly-chromatic opal. This variety is semi-transparent.

An opaque milk-white variety seems composed of chalcedony charged with "quartz nectique." This sometimes adheres to the tongue.

A third very rare variety with a tufted structure may contain a fibrous zeolite.

The cacholong of white onyx is *milk opal;* the loss of its small content of water makes it more or less opaque.

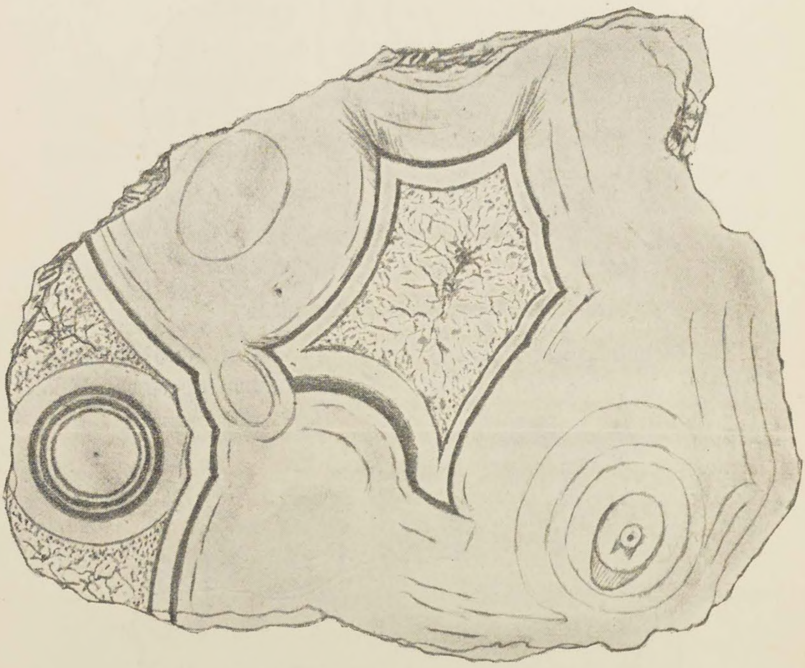

Fig. 10.—Fortification Agate, with Sectioned Stalactites.

CARNELIAN.

True carnelian, or red-tinted chalcedony, is exceedingly rare in Scotland, the colour of the red-tinted bands of Scottish agates being due to a multitude of spots of a ferruginous silicate, which have segregated out of a stained chalcedony. These red spots are frequently replaced, with amazing suddenness, by others of an equally brilliant yellow, or both will equally suddenly disappear—the band which carried them appearing as if bleached.

Fortification Agates.

The mammillated structure which the layers of an agate assume when they line rugose surfaces increases in size with every successive layer, so that towards the central parts of an agate sharp re-entering, but curvilinear, angles lie between these mammillations. Should one or more of the succeeding layers be cacholong or sard, these, taking as it were a cast of such re-entering angles, when cross-sectioned appear with salient projections, and resemble the rectilinear parapets of a fortification (figs. 10 and 11).

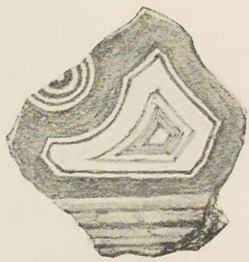
Fig. 11.—Fortification Agate.

Entrance of Solution.

That the siliceous solution entered uniformly round the whole surface of the druse would seem evident from portions of the skin having been frequently forced into the cavity throughout its whole periphery, and from these having been sheathed in clear chalcedony upon *both sides* of such portions, forming a false moss agate. This envelopment of the intruded skin is either immediate, or the clear chalcedony is seen to invest both the skin and a previously deposited layer of chalcedony, which had, previous to their intrusion, lined the *inner* surface of the disrupted fragments.

The Tube of Escape.

The liquid which holds the chalcedonic material in solution is forced by endosmose through the several layers of chalcedony, along the divergent tridymite fibres. After the deposition of its content of silica, it is forced out of the cavity by the accession of a new supply of chalcedonic solution passing inwards from all sides of the agate. The now de-silicified liquid escapes through one or many tubular openings; these are disposed at every part of the surface-cavity, but very rarely near its base. Frequently this opening is linear, with a false appearance of being a rent; and not infrequently a linear projection on the surface of this agate follows the course of the opening.

The thickness of each layer of deposited material invariably diminishes as it approaches the "tube of escape." This tube, with the dilatation which frequently occurs thereon, is the last portion of the cavity to be filled; and in that portion which passes

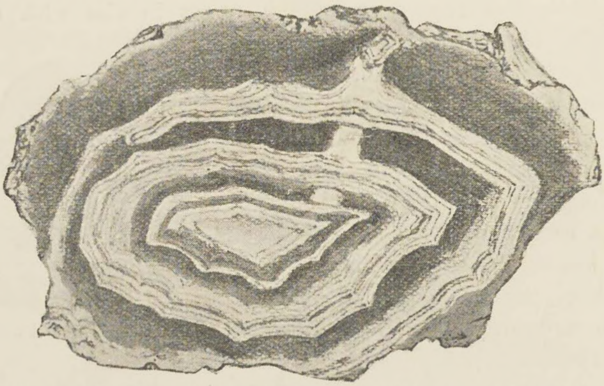

Fig. 12.—Cacholong and Chalcedony Agate, with one Tube for all the Cacholong Layers.

through the outer clear chalcedonic layer, it is of microscopic dimension—almost invisible to the eye—and it most frequently remains open (figs. 12 and 13), and may become a rent.

Dilatation on the Tube.

In almost all cases there occurs on the tube of escape a dilatation of considerable size. This is situated near the point where the tube reaches the earliest deposited layer of chalcedony. It is filled somewhat posteriorly to the centre of the agate, but generally with the same material—quartz. Occasionally it alone contains cacholong, and very rarely it alone contains onyx.

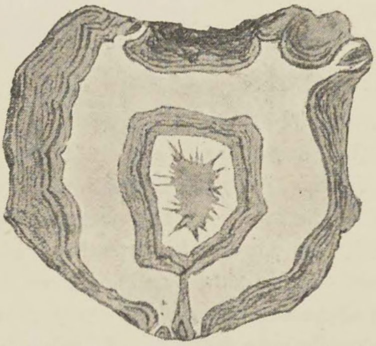

Fig. 13.—Cacholong and Carnelian Agate, with two Tubes for the Cacholong and one for the Carnelian Layers.

No attempt has been made to explain this dilatation, although probably the whole secret of agate formation is connected with its presence. It resembles the congestion which takes place when a stream of individuals is arrested at a narrow exit (figs. 14 and 15).

Fig. 14.—Dilatation of the Tube, filled with the same material as the centre : Quartz.

ABNORMAL STRUCTURES.

Onyx.

The adhesion of the layers of deposit of pure chalcedony to one another is so great that gravitation does not interfere appreciably,

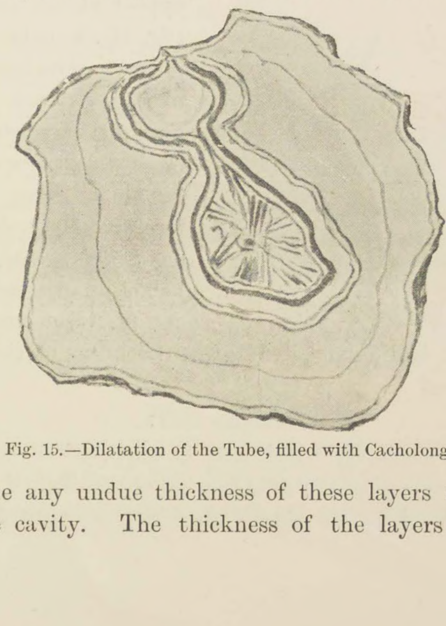

Fig. 15.—Dilatation of the Tube, filled with Cacholong.

or determine any undue thickness of these layers at the lower part of the cavity. The thickness of the layers which form so-called "stalactites" is no greater at their pendulous extremities than elsewhere. In the case of others of the materials which go to the formation of agates, however, there is so much feebler an adhesion both to chalcedony and to each other, that gravitation interferes to a marked extent, so that most of the coagulating material is found at the lower part of the cavity, and a zonation or parallel banding of cacholong, sard, opal, quartz, and chalcedony appears—forming horizontal layers or bands in the lower part, or less frequently in the greater part, of the remaining cavity. This banded structure, from a resemblance to the human nail, is termed *onyx*.

The layers of an onyx, especially those consisting of cacholong and opal, are occasionally nearly an inch in thickness; but, however wide, each band is continuous round the whole upper part or "dome" of a cavity, though they are there of *extreme tenuity*. Opal in this acts exceptionally, remaining apparently absolutely as a band at the floor of the cavity. In many chalcedonic druses the dome remains unfilled.

Should purer chalcedonic substance succeed the cessation of onyx formation, the upper part of the cavity is again lined with layers of uniform width, or a second onyx structure may appear at the actual centre (fig. 16: see also fig. 3).

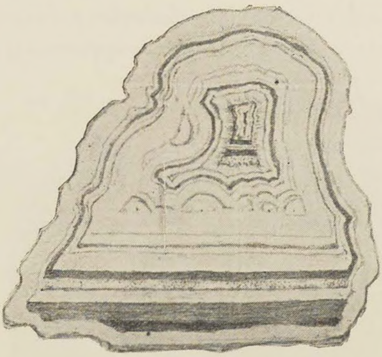

Fig. 16.—Onyx Agate.

Onyx structure is invariably horizontal, and so it *discloses the position which the agate occupied in a rock*. Should an inner, and therefore secondary, deposition of onyx appear in which the bands lie in a position different from the first, it shows that the rock had been tilted before the filling of the druse had been completed.

Plynthoid Onyx.

During the shrinkage which may be supposed to be associated with, or to accompany, the solidification of the chalcedonic matter, and which shrinkage in certain cases may account for the easy separability of the layers from one another, it may be seen that, as a general rule, the parallel layers which go to form onyx do not obey the usual law. These layers rend *vertically*, and the material which forms them concretes laterally into, as it were, a series of brick-shaped bodies. The spaces intervening between

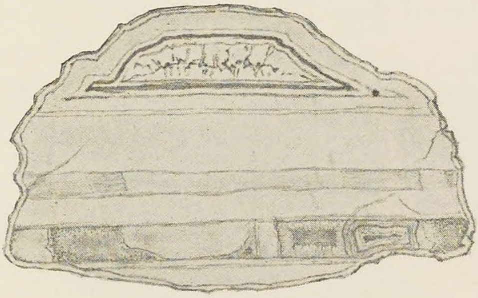

Fig. 17.—Plynthoid Agate.

these, if they are mere rents, are subsequently filled with chalcedony; if they are wide they are either at the time of the concreting filled up with rock crystal, which has separated from the chalcedony or cacholong,—or else they are thereafter plugged with independently-formed agates of more or less rectangular shape (fig. 17—lower part).

Wave Onyx.

In these the various layers have not, in solidifying, been rent asunder by transverse planes of division, but have assumed curvilinear outlines at their fringes. Overlying layers have been deposited successively in the hollows between such fringes, so that this structure, when seen in section, presents an appearance similar to that of tumbling waves or of hummocky ice (fig. 18).

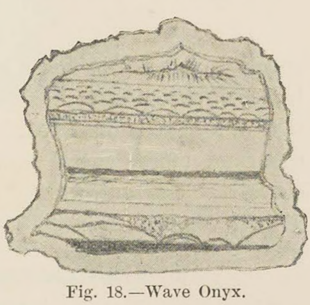

Fig. 18.—Wave Onyx.

Eyed Agates.

Occasionally—but very markedly at certain localities only—after the deposition of the first thin layers of chalcedony, a number of the succeeding layers are not disposed uniformly over the inner surface, but are confined to one or more spots, where a slight roughness, or a thickening of the skin, seems to exercise an undue amount of adhesion,—or even of attraction. Around, or over, this spot (or spots) the succeeding layers are, during a brief succession, exclusively deposited—hence assuming a hemispherical form. Cacholong, or carnelian, when present,

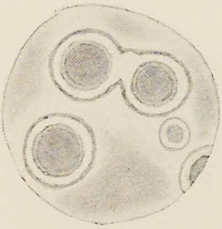

Fig. 19.

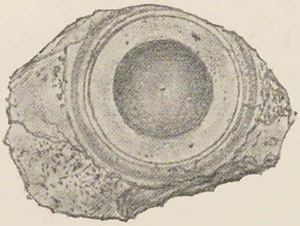

Fig. 20.

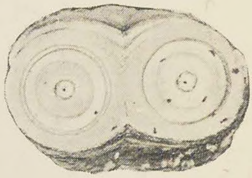

Fig. 21.

Cross Sections of Eyed Agates.

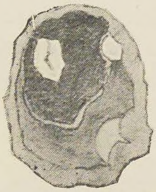

Fig. 22.—Section of Cacholong Eyes.

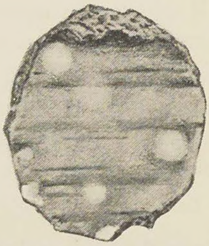

Fig. 23.—Cacholong Eyes, inside Skin of an Inky Onyx.

generally is seen in these hemispherical layers, alternating with layers of chalcedony; so that, upon sectioning, an appearance like that of an eye is disclosed. Such "eyes" occasionally, but rarely, occur on more central layers. Not unfrequently they are, to a considerable extent, formed of an impure fibrous calcite (figs. 19, 20, 21, 22, and 23).

ABNORMAL STRUCTURES IN THE LAYERS.

That the gelatinous chalcedony of the layers is not rigidly solidified immediately upon its separation from the solvent is shown by the concreting at certain spots of substances which may be regarded as having been dissolved in or held in suspension in the chalcedony solution. Through the segregation of these certain isolated, and apparently suspended, structures appear in the layers of deposit. Agates exhibiting these are termed discachatæ—oonachatæ—hæmachatæ.

DISCACHATÆ, OR DISC-BEARING AGATES.

The layers of agates very infrequently consist of the *pure* material of the several varieties of silica of which an agate is built up. Very generally there is some admixture—as of chalcedony with opal, or *vice versâ*,—of chalcedony with cacholong, or of chalcedony with a ferruginous silicate.

Fig. 24.—Disc-bearing Agate.

When the amount of such admixture exceeds a certain limit there is a concretionary separation of that substance which occurs in *smaller* amount,—and the concretionary forms are characteristic. The clouded milky appearance of some chalcedonic layers, due to uniform diffusion of cacholong, is cleared up as it were, in some parts of the layer, by that substance having been concreted laterally around a spot of roughness, or difference of substance. When this concreting is confined to one layer, one or more opaque milk-white discs result (fig. 24).

Oonachatæ, or Ovoid-bearing Agates.

There are two varieties of these—chalcedonic, and cacholong. Both result from the concreting of a small portion of one substance which has been suspended in, or mixed with, an excess of another. In both there is the assumption of an egg-like form, but the structure of these is very different.

Such shapes when formed of chalcedony occur in milk opal, and have a fibrous structure which radiates from the centre uniformly in every direction (fig. 25).

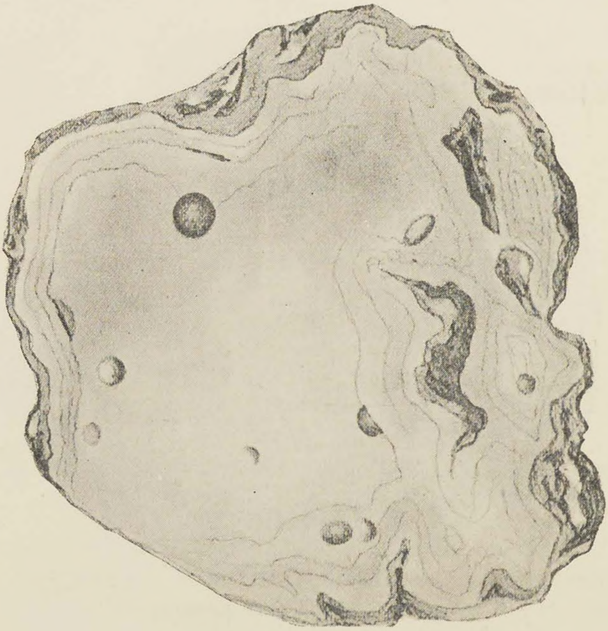

Fig. 25.—Disc-bearing Agate.

When formed of cacholong they occur in chalcedony, and the form results from the superposition of a system of discs (see discachatæ), one over the other, in successive layers. The pre-existence of a disc in a layer of earlier deposition seems to determine the formation of others in superposition. The relative size of these discs increases with successive layers and thereafter again diminishes, so that a solid opaque ovoid suspended in clear chalcedony results. Occasionally each alternately succeeding layer is uniformly clear, so that a series of opaque white discs, successively enlarging and then successively diminishing in size, is here presented (fig. 26).

HÆMACHATÆ,

agates, with blood-red discs,—or with spots, approaching in form more or less to perfect spheres. Such are formed in red-tinted chalcedony in the manner already described in connection with disc-bearing and ovoid-bearing agates. Frequently the ferruginous silicate assumes an annular form, which is merely the periphery of a colourless disc (figs. 27 and 28).

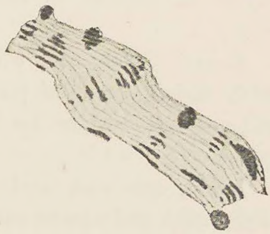

Fig. 26.—Discachatæ and Oonachatæ.

HÆMA-OVOID AGATES,

result from one abnormal structure being present within another. The milky material, segregated apart to form the discs (whose superposition in varying size results in an ovoidal structure of cacholong), contains within itself red colouring matter, which has separated in each disc into a series of rings which are made up of red discoidal spots. As these rings of dots are at the same distance from the circumference of the discs, it results that each

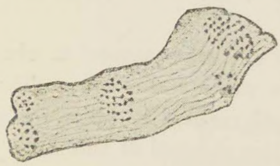

Fig. 27.—Hæmachatæ Ovoids.

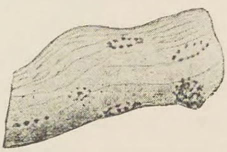

Fig. 28.—Hæma-Ovoid Rings.

ovule displays upon *longitudinal* section either a single dot ring, or a system of red oval dot rings,—as well as either a single dot ring, or a system of circular dot rings upon *cross* section (fig. 28).

Red or carnelian agates are frequently sprinkled throughout with lustrous spheres which resemble drops of yellow oil. As these show no varying colours in the polariscope they cannot be opal.

CRACKS IN AGATES.

First.—The rock may have been rent—dislocated by a latera. shift—and re-cemented, so as again to contain a tight cavity, before the endosmotic filling of the latter. In such cases the layers of deposit in the agate follow the dislocation of the rock.

Second.—The rock, with included agate, may have been rent with dislodgement of parts, and these may have been thereafter re-cemented either by a new access of chalcedony, or of calcite.

Again, the rock and agate may have been shattered, with dislocation and almost inversion of fragments—with extrusion of some—or intrusion of the matrix or of jasper, and re-cementation by clear vein-like chalcedony. Very rarely when the fracture occurred before the cavity of the agate was entirely filled, the subsequent layers folded into the rent and effected a re-union.

At certain localities the agates are frequently divided by a straight rent, and one portion entirely removed.

Recent open cracks are probably due to frost.

ALTERATIONS OF COLOUR.

Agates may be naturally or artificially stained. They may also be bleached.

Open cracks frequently convey ferruginous waters which stain agates elsewhere colourless,—or, carbonated waters which bleach red-tinted stones.

The loss of the small amount of water present in chalcedony renders its translucent structure white and opaque. The loss of the large amount present in opal renders it white, opaque, and granular (*quartz nectique*); and the removal of this loose powder by water splits up an onyx into plates of chalcedony which exhibit an ovoidal or micro-mammillated surface.

The appearance of the commoner varieties of agates may be improved by artificial staining. Chalcedony absorbs staining liquids. Cacholong, opal, and quartz do not. Colourless chalcedony may be stained dark-brown by being heated in a strong solution of honey, which is after-carbonised in its pores by sulphuric acid. The stain penetrates to about the fortieth of an inch.

MOCHA AGATES.

Mochas are agates between the layers of which water—carrying manganesian or ferruginous matters in a state of minute division—has penetrated. Upon the evaporation of the water, the intruded solids have been deposited in an arborescent form. More rarely this deposition is in cracks.

JASP AGATES.

Stalactites of celadonite, or other "skin-material," are invested by a thick layer of colourless, or by jasperous, chalcedony. This chalcedony holds, as it were in suspension, multitudes of spheres of carnelian. This structure-within-structure shows that the deposited layers of chalcedony do not, immediately after their

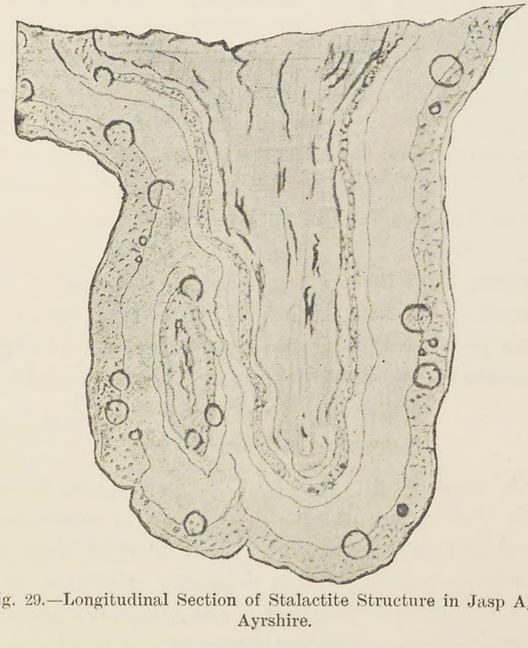

Fig. 29.—Longitudinal Section of Stalactite Structure in Jasp Agate, Ayrshire.

deposition, concrete into a solid, but allow of motion sufficient for the formation of an independent structure within their substance. Anomalous as such an arrangement may appear, the structure of these spheres is still more so, as many of them show that their colouring matter is disposed so as to simulate the whorls of a volute. They thus occasionally present a certain resemblance to minute ammonites. Jasp agates are usually vein agates (figs. 29 and 30).

Stalactitic Jasp Agate.

In this, the more common variety of jasp agate, the stalactites which impart the prevailing characteristic are disposed in the same nearly-parallel arrangement which is seen in ordinary stalactitic agates—being pendulous from the upper part of the vein. In many cases where there has been an excess of celadonite or other basement material of these stalactites there is a greater or less approach to the structure of moss agate. When the fibrillæ which determine this structure are separated to any great extent, the ordinary agate arrangement of successive layers occurs; even a central mass of quartz occasionally presenting itself.

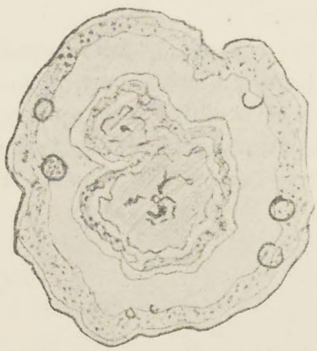

Fig. 30.—Transverse Section of Stalactite Structure of Jasp Agate, Ayrshire.

When, again, the moss agate structure is unusually close, there is an approach to ordinary jasper. When central vacuities occur in this, the parts margining these vacuities are sheathed by a layer of carnelian—the centre being here filled with a manganesian calcite.

Brick-shaped Jasp Agate.

At the Ayrshire locality which yields jasp agate, a prevailing structure is that of a vein agate which has been cross-rent into brick-shaped segments. The rents which intersect these veins are filled with impure manganesian dolomite, which is the lining material of the veins themselves. The coagulating silica which fills these rectangular spaces has thereafter concreted so as to line the sides with layers of brilliant red, yellow, pink, and white colours—these colours being usually deposited in a system of minute spots. Thereafter these *brick-shaped* structures have themselves frequently been rent—these secondary rents being also filled by a dolomitic paste.

True jasper very rarely forms layers in an agate: when it occurs it invariably is confined to a small portion of the periphery, being deposited somewhat after the manner of an "eye."

Note.—The accomplished author of the preceding paper, Dr. Heddle, died, after a long illness, at St. Andrews, on the 19th November, 1897. He had gone over a first proof, and had finished most of the drawings to illustrate it before his death, but it had to be held over from the previous part of the *Transactions*. Ed., 1900.