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THE BILLITONITES

(AN ATTEMPT TO UNRAVEL THE TECTITE PUZZLE)

BY

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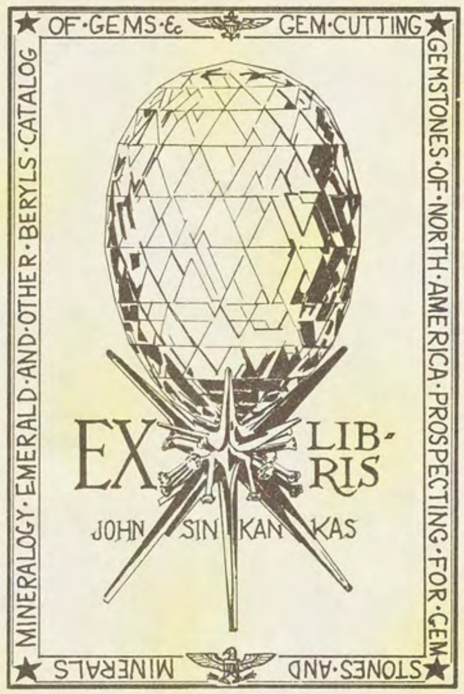
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PART I.

PREFATORY MATTER.

General Remarks.

FRANZ SUESS at Vienna (**14**)[1]) in 1900 proposed to incorporate with the meteorites the bodies hitherto known as Moldavites, Billitonites and Australites as a new group, the glassy meteorites or *tectites*, because, in his opinion, the cosmic origin of these bodies could hardly be doubted. At a later date the newly discovered Queenstownites, the Americanites and the Schonite joined the said company.

SUESS's proposal was not generally accepted. Especially in the articles related to the subject and written in English idiom, the term *obsidianites*, initiated by WALCOTT (**19**) is more frequently used.

The first term means ,,fused''; the second term, though invented to express no definite meaning, yet strongly suggests the idea of a volcanic origin. Therefore the latter can scarcely make pretension to be more neutral than the former. In the sequel of the present paper the term ,,tectites'' will be used, but simply for convenience, as a collective noun.

In order to give the reader some orientation as to the present state of the tectite matter, a summary of existing information may precede.

The tectites are small glassy bodies which owe the greater part of the attention with which they have always been considered to two properties: their peculiar geological and geographical location, and the very distinct sculpture of their surface. As for the latter, I beg to refer to the papers mentioned marked with an asterisk, and to the plates printed with this article.

In the various countries where the bodies are met with, geologists as well as chemists and physicists have all studied them closely and attentively for more than a century and a quarter and from several points of view, with the remarkable and queer result that the opinions regarding their origin differ nowadays just as much as they did fifty years ago.

Occurrence.

The *Moldavites* (**14**) are found in the area southwest of Budweis (south Bohemia) and in the surroundings of Trebitsch (southwest Moravia), the two groups of localities being separated about 100 km. The bodies lie everywhere on plateaus at an altitude of from 400

1) The numbers in bold type are in consonance with those of the references.

to 500 m. above sea level in a superficial layer of gravel, the age of which is probably late-Tertiary, at all events pre-Diluvial (**15**); they have never been discovered in the valleys.

The *Billitonites* occur in the southern half of Billiton (Malay Archipelago) in the so-called alluvial or stream-tin deposits (the kolong mines) which, however, may be of early-Plistocene, perhaps of late-Tertiary age. According to VERBEEK (**18**) their site is beneath the overburden of sand and clay; they have never been found at the surface or in the eluvial tin deposits (the kulit mines). It is to be observed that this statement is based upon the information given bij the Chinese miners. These men informed me that the black bodies lie without exception at the base of the tin deposit, immediately upon the bed-rock (granite, slate, quartzite), and the only one of the European functionaries who had collected with his own hand a few pieces in their original site, confirmed this statement. Merely as a consequence of the manner in which the deposit is removed, the bodies are only occasionally picked up in the diggings (kollongs); generally it is not until the former is treated in the box-sluice (bandar) that the latter may become conspicuous enough to be collected. Evidently, many of the smaller ones are washed away with the tailings and are lost for ever; besides, since the tin-wash is continually drawn up against the water current by means of iron implements, the glassy stones run no small risk of being damaged.

As I stayed only a few weeks in Billiton and had a lot of other things to do, I couldn't think of carefully examining the tin deposits nor of watching the treatment of the tin-wash. I had to confine myself to a close contemplation of some large private collections and, by the assistance of several officials of the Billiton Tin Company to whom I express once more my deep gratitude, I was enabled to take with me a number of 115 selected pieces in order to study them at home at my leisure. Moreover, I got some ample and reliable information as to the mode of occurrence of the bodies in various districts. From this can be inferred 1), that their general habit slightly varies with the districts and 2), that the occurrence of nests of Billitonites (see hereafter), though not really ascertained, is at least possible and might perhaps be called probable.

Bodies of similar form and, as far as it is known, of similar properties too, were met with in some tin mines in the Federated Malay States (**11**), near Tutong in British North Borneo (**8**), in the island of Bunguran, forming part of the Natuna group (**6**), in the gold and diamond placer-mines of southeast Borneo (**18**); on the lower slopes of Mt Muriah, Java (**18**) glassy bodies were found with deviating properties.

The *Australites* or Obsidianites proper (**3**, **13**, **19**) are scattered over nearly the entire southern part of the Australian continent and over part of Tasmania. Some of them were picked up from the surface, but the bulk came from the shallow gold workings in South and West Australia and in Victoria and from the shallow tin workings in Tasmania. Their presence in deep leads, though reported, has never been verified. According to PETTERD (**10**) they often occur in Tasmania in nests of from 17 to 50 pieces of various forms and sizes.

The localities in which they are found lie at altitudes up to 1000 m. above sea level. The geological age of the including strata may be about the same as that of the Billiton tin deposits. The extreme eastern and western localities are separated by a distance of about 3000 km.

SUMMERS (**17**) proposed a division of the Australites into five "provincial types", the physical and chemical properties of which are more or less dissimilar.

All around Mount Darwin in Tasmania, but exclusively in a narrow strip of territory situated at an altitude of from 275 to 400 m., tectitic bodies occur differing in many respects from the common Australites. FR. SUESS (**15**) proposed to term them *Queenstownites*; they are disseminated in a layer of gravel, but at most at a depth of 20 cm. beneath the surface.

JEŽEK and WOLDŘICH describe (**4**) vitreous bodies of American origin (Clifton in Arizona and Cauca valley in Columbia) which, according to text and figures, belong to the tectites, but their chemical composition is unknown. In expectation of the necessary analyses they may be called *Americanites*.

Finally, a body found in Schonen (Sweden), with an uncommonly high specific gravity, is termed *Schonite* by FR. SUESS (**15**) and is provisionally ranged among the tectites.

Some general properties.

Nearly all tectites consist of a yellowish, brownish or more greenish glass. The Australites and Billitonites are black by reflected light and become transparent only in thin splinters. The Moldavites already acquire transparency in rather thick slices. Among the Queenstownites many specimens are perfectly translucid, whereas others are enamel white.

In very thin slices the glass loses its colour almost completely and the microscope does not reveal a trace of heterogeneity nor of devitrification.

Most tectites are more or less distinctly and finely banded in a characteristic cloudy way; this feature is commonly attributed to fluxional structure. A few small vesicles are at times visible in the slices, especially in those of Moldavites. Here also larger cavities can often be seen with the naked eye, and in some cases Queenstownites show a regular blebby glass.

Fr. Suess (**14**) published drawings of broken up Moldavites in which a large vesicle once occupied almost the whole interior, leaving but a relatively thin shell of glass. Among the Australites three of such hollow specimens have been found (**3**, **13**, **17**); one of them was sawn through, but no measures were taken to collect and analyse the gases which probably were enclosed in the cavity; another one contains two large vesicles separated by a thin partition (**15**). Walcott (**19**) writes: "The interior of the cavity is perfectly smooth and has a high polish. The few vesicles, contained in the wall, are small and spherical. Had the Obsidianite been produced from a fragment of lava rich in gaseous components, the walls would surely have been highly vesicular".

A couple of fragments belonging to my own collection of Billitonites show pretty large concavities with a smooth and gleamy interior (*14*) [1]), which suggests the idea of a former cavity, part of a hollow body, and this is the more remarkable, since vesicles, even of microscopic size, are very rare in Billitonites.

All Queenstownites seem to be irregularly shaped; often they are very odd in appearance (**15**). In a lesser degree the Bohemian bodies possess the same peculiarity (these often look as if they are sherds) whereas among the Moravian Moldavites many tolerably regular specimens occur; according to Fr. Suess (**14**) those of Dukowan and Skrey often differ more from their Bohemian neighbours than from Billitonites. The latter are as a rule of a more regular shape, and so are the Australites, but among these some particular forms abound which are never or seldom found among the Billitonites, *viz.* buttons and dumb-bells or time-glasses; the latter gradually pass into somewhat elongated ellipsoidal bodies (**3**). (see p. 28.)

The regularity of the shape and the amount of vesicles might depend upon the chemical constitution of the bodies, which will be spoken of subsequently. It appears as if a greater acidity leads to decrease the former and to increase the latter.

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[1]) The numbers printed *in italics* refer to the plates.

The melting point of the tectites is high. Small bars of Billitonites bend at 800° C. when lightly pressed, and at 880° C. without any pressure. At 1050° C. they assume the form of the vessel in which they are treated, and they actually melt between 1200 and 1250° C. The M. P. of an Australite was fixed at about 1324° C.

Moldavites heated up to 1000° C. did not soften; at 1250° C. a grey opaque pellicle appeared, and it was not until about 1400° C. that quiet melting took place.

Queenstownites are doubtless still harder to melt, though experience is wanting.

Bareš (14) heated a number of Moldavites [redacted] till they began to show indications of weakness and then, suddenly, he threw them into snow. Most of the bodies stood the test and remained unaltered; only a couple of them were broken up into a few pieces; it is evident that common glass and even obsidian would have burst into shivers under these conditions.

The hardness of the tectites is somewhat above 6, but never in the least reaches that of quartz.

The relative densities are as follows:

Queenstownites	2,284—2,292
Moldavites.	2,303—2,385
Americanites.	2,344—2,355
Australites	2,367—2,428
Billitonites	2,443—2,490
Schonite	2,707

The absolute weight of the tectites is always small. Two Billitonites pertaining to the collection of the Raffles Museum in Singapore are said to weigh 464 and 316 grms. (**17**); both are of unknown provenience, but without doubt such giants are exceedingly rare. Of my collection the largest body weighs a little upwards of 80 grms. and the large cylindrical Billitonite (*1*) in the Amsterdam Museum is slightly below that amount. But the bulk is very *far* below it: 50 per cent of my own pieces weigh less than 10 grms. and 85 per cent of them less than 30 grms.

Similar values seem to prevail with the Australites and Moldavites. Of the more than 1000 Moldavites reviewed by Fr. Suess, the largest had a weight of 122 grms. and the heaviest Australite is recorded to weigh 120 grms. The Queenstownites are on an average still lighter.

The smallest tectites are said to be of a pea shape; this minimum agrees with that of the common meteorites, but their maximum weight is but a small fraction of that of the indisputably cosmic bodies.

Hypotheses concerning the origin.

It may be observed beforehand that the various groups of tectites, although differing in many points, doubtless belong to one and the same large family and, consequently, must have had a similar origin. It is therefore inadmissible that a hypothesis concerning the origin should be propounded only with a view to one of the groups, excluding all the others. On the other hand, it must be expected from a general hypothesis that it enables to account for the diversity of properties of the various groups. These desiderata have not always been taken into consideration.

As a matter of course the first investigators only discussed a *terrestrial* origin, and in this respect the two following possibilities were thought of, *viz.* it was supposed that the Moldavites (which were discovered first) are *artificial products* (artefacts) purposely made or not, *e.g.* main- or by-products (slags) of the manufacture of glass or metals, or the bodies were considered to be *acid ejectamenta* of volcanic eruptions, and as such belonging to the obsidians.

The many objections that could be put forward against both possibilities, induced VERBEEK (**18**) to assume a *non-terrestrial* origin and, moreover, he judged it by no means improbable that the bodies might have been shot forth as bombs by the moon volcanoes[1]).

The general opinion did not comply with the latter half of this hypothesis, but the chief idea was taken up first by KRAUSE (**6**) and afterwards by FR. SUESS who, principally in two elaborate and minute memoirs (**14**, **15**) propagated the *cosmic* or *meteoritic* origin of the tectites.

It was not so much from conviction as from want of another plausible explanation that SUESS's idea was accepted by many investigators. A positive and conclusive proof in favour of this origin could, however, not be afforded.

I will presently attempt to prove that none of the hypotheses mentioned can hold their own against an objective criticism, and in this effort I shall leave alone, on account of their variety, the superficial ornaments of the bodies, and deal only with the chemical and physical evidences.

We dispose of a great many data to compare the tectites with the acid volcanic vitreous rocks but, as to the latter, we will confine ourselves to the obsidians as the only ones that, practically speaking, contain no water.

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[1]) As a relic of this proposal the bodies are colloquially called "moon balls" in Billiton.

The relative density of obsidian ranges from 2,34 to 2,42 and is about the same as that of the Australites.

When tectites are heated, they simply pass through the successive stages of viscosity and finally melt quietly. As a rule the obsidians behave otherwise. When they become white hot at about 1000° C. they suddenly intumesce, taking from 2 to 15 times their original volume, and this feature is accompanied by an outburst of gases and by formation of pumice, which melts when put to a higher temperature. Some rare obsidians do not observe the rule; it should be ascertained whether these perhaps are pseudo-obsidians, in reality pertaining to the tectites.

The bulk of the obsidians do not consist of pure glass. Microscopic examination always reveals a more or less pronounced devitrification. Here also the few exceptions to the rule might turn out to be tectites.

The chemical constitution — a matter of importance — is exhibited in the following table; each couple of two numbers indicate the maximum content and the minimum one of the proper substance in *per cent* of weight.

	Queenstownites.	Moldavites.	Australites.	Billitonites.	**Obsidian.**
SiO_2	88·8 / 89·8	77·7 / 82·7	69·8 / 77·3	69·8 / 71·1	68·5 / 76·2
Al_2O_3	6·13 / 6·2	9·6 / 12·9	10·— / 15·—	12·— / 14·3	10·2 / 16·—
Fe_2O_3	·— / .3	·— / 2·1	·3 / ·9	·— / 1·1	·— / 4·2
FeO	·9 / 1·2	1·1 / 3·4	3·8 / 5·3	5·3 / 5·7	·— / 2·1
MgO	·6 / ·8	·2 / 1·5	1·6 / 2·5	2·4 / 3·2	·1 / 1·4
CaO	·— / ·2	1·3 / 3·1	2·4 / 3·8	2·4 / 3·8	·— / 2·1
Na_2O	·— / ·1	·3 / ·8	1·— / 1·5	1·2 / 2·5	3·5 / 5·5
K_2O	1·1 / 1·4	2·2 / 3·3	1·8 / 2·6	1·9 / 2·8	1·8 / 5·1

At first sight the difference between obsidians and the more basic tectites is not striking. But apart from the fact that the maximum amount of silica in the former is surpassed by the minima in the

Moldavites and Queenstownites, more characteristic differences are brought about by the proportions of the two alkalies, and by the sum of the potassium and sodium oxides relative to that of the lime and magnesia.

If the tectites are subjected to OSANN's method of projection in an equilateral triangle (**9**) in the same way as the real igneous rocks, the difference becomes very striking indeed. The result is illustrated in Fig. 1. The tectites, being always substances of high acidity, get located partly outside the limits of the igneous rocks, partly within the basic members of them, but all are distant from the obsidians. This strange behaviour can, methinks, only be interpreted in one way: t h e t e c t i t e s d o n o t b e l o n g t o t h e t e r r e s t r i a l i g n e o u s r o c k s.

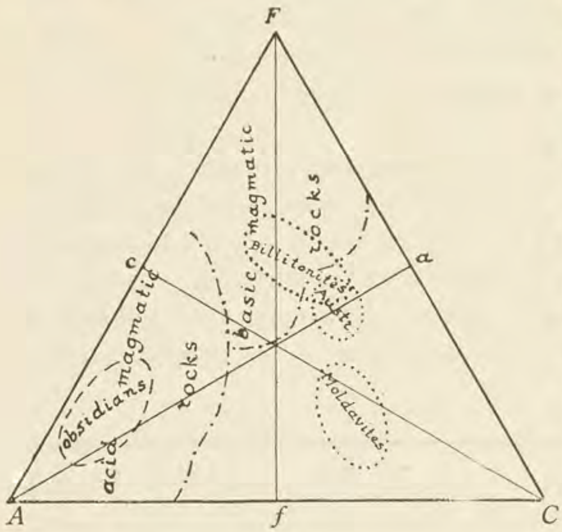


Fig. 1.

In this connection the experiments of A. BRUN at Geneva are also very interesting (**1**). He carefully analysed the gases which escaped when various vitreous substances were heated up to 900 or 1000° C. The principal results are grouped together in the following table, in which the weights and volumes are on the base of one kilogram of substance treated. (See table next page).

The strikingly different composition of the gases also points to an origin of the tectites other than that of the obsidians.

Finally it is not to be forgotten that the principal groups of tectites are met with in territories lying at enormous distances from younger volcanoes having yielded acid products, whereas any subsequent transport, either by land or by water, need scarcely be discussed.

BERWERTH (**2**) set forth the objections which may be raised against a meteoritic origin and, on the other hand, FR. SUESS (**16**) summarized those which had arisen against BERWERTH's conception of the tectites being artificial bodies. For completeness' sake I will briefly mention the chief arguments on both sides.

The geological age of the sediments carrying the tectites is so remote that, if Man had already made his appearance, his civilisation

	Obsidian from Java.	Billitonite.	Moldavite.
I. Solid sublimate of: chloride of ammonium	50 mgms	5 mgms	trace
chlorides of potassium and sodium.	a little	60 „	„
II. Total amount of gases.	417 ccs.	213 ccs.	175 ccs.
The volume percentages of the constituent gases are as follows:	per cent	per cent	per cent
Cl chlorine	14.47	—	—
HCl hydrochloric acid.	50.75	—	—
SO_2 sulphurous acid	8.31	0.18	—
CO_2 carbon dioxide	9.83	46.—	17.—
CO carbon monoxide.	} 15.21	47.13	63.—
N nitrogen		trace	} 20.—
H hydrogen.		6.66	
O oxygen	1.43	—	—

was on so low a degree that an intentional manufacture of such hardly fusible glassy products must be considered impossible. Even, it being admitted that one human tribe or another could have, by mere chance, succeeded in making such products, it is still inadmissable that the different tribes populating (perhaps) the so widely distant parts of the globe as Bohemia, Billiton and Australia, should have had similar chances. Moreover, in the latter two countries no traces of a former glass or metal manufacture (as in Bohemia) have been brought to light. Wherever objects of the pre-historic stone-age have been discovered, they are hewn of common natural rock; only in some spots in Austria and Moravia, not far away from the well-known Moldavites, a few fragments of these were found scattered among the rock fragments.

The advocates of a cosmic origin suppose the tectites to be parts of the salic outer shell of the meteoric or planetary bodies from which the meteorites are said to originate. Against this supposition the following arguments may be advanced. The character of all the meteorites proper is exceedingly basic; they consist either of (iron and nickel) metal or of minerals poor in silica; some of them are aggregates of both substances. There is, indeed, a (continuous or discontinuous) outer shell of acid salic matter around the earth's basic simatic nucleus. But, first, it is by no means necessary that a similar shell exists around the much smaller mother-bodies of the meteorites, because, in case these bodies are really enveloped by an atmosphere, it must be one which is much poorer in oxygen than that of the earth. Secondly, it is obvious that this salic shell, if existing, cannot be more acid than the earth's shell, whereas the silica content of many tectites surpasses that of the most acid among the terrestrial igneous rocks. Thirdly, just as well as rocks being composed of a mixture of sal and sima are not uncommon on earth, likewise meteorites of a transitional nature ought to occur, but hitherto they have not been discovered. Fourthly, it remains unexplained why the acid tectites never fell within historic time, whereas a considerable number of common basic meteorites are known to have fallen in that period.

Many more arguments might be put forward, but I think the preceding are convincing enough to account for the truth of the sentence: none of the hypotheses set up to the present time is acceptable.

The origin of the tectites has still to be traced.

Before concluding this chapter I will call attention to the fact that in R. H. WALCOTT's paper (**19**) many remarks have been made which tally with my own ideas and observations. After having elaborately discussed the various theories, his two final sentences run as follows: "It is therefore important that all other possible explanations should be thoroughly investigated and exhausted. If this is done and they are alle dismissed as untenable, we should, I think, be justified in attributing a cosmic origin to them." It was just because one of the terrestrial possibilities, *i.e.* the one discussed in Part III of this paper, did up to now not enter one's mind, that the cosmic origin, though only based on negative evidences, was accepted by many students.

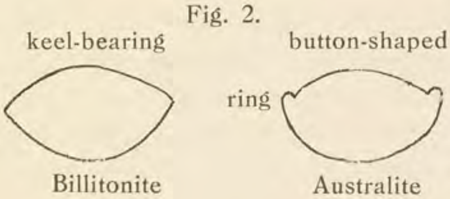
PART II.

MORPHOLOGY OF THE BILLITONITES.

All the principal shapes are represented on the plates. The predominant fundamental form is the triaxial ellipsoid; particular varieties of this form are the sphere and the cylinder with hemispherical endings (*1, 15, 27*) [1]. More or less flattened sides are rather common and ellipsoids with one flat side, imitating the shape of an echinoid (*40*), are frequent. Transitional forms occur in all directions. Much rarer are specimens resembling a tear or a pear (*3, 5, 29*) or a dumb-bell (2) and only exceptionally low-shaped, flattened, rudely triangular bodies (*10*) are met with.

Typical for the Billitonites is the relative frequency of a sharp peripheral ridge or keel (*4*), often degenerating into a narrow curved strip or keel-zone (*22, 36*) and causing a strong impression of the body being composed of a lower and an upper half. Sometimes only part of the circumference is built as a ridge whereas the rest is developed as a strip, both features graduating into one another. The keel-bearing bodies remind one of the buttons among the Australites (Fig. 2) and the two forms may have been generated in a similar manner.

Fig. 2.



To my collection belong several fragments and pseudo-fragments which will be spoken of subsequently.

A most characteristic feature of the Billitonites is the sculpture of the surface, which is different from that of all other groups of tectites, as appears from a glance at the brilliant photos published by Fr. Suess (**14**). Krause (**6**) gave a more complete description of this sculpture than Verbeek (**18**), but in places the former's text is somewhat partially affected by the author's opinion in favour of a meteoritic origin. Moreover, the Leiden collection, on which Krause's paper was based, though containing some fine and instructive specimens, is still by far the inferior to my own collection with regard to number, varieties and completeness of ornamentation. I have therefore deemed it necessary to go briefly over all details, describing them simply as they are seen and entering as little as possible into any question bearing on the origin [2].

The most conspicuous ornaments are: 1. *navels* (*22, 28*), 2. *gutters* (*11, 16*), 3. *grooves* (*35*), 4. *funnels* (*15, 30, 31*), the complex of which not seldom cover a considerable part of the surface. The rest of the latter may be called the *background*; this is ornamented in its own particular way and in one of the following manners, *viz.*

[1]) Numbers printed *in italics* refer to the figures on the plates.

[2]) I am indebted to the Professors of Geology Dr. K. Martin at Leiden and Dr. E. Dubois at Amsterdam who graciously permitted me to study the collections of tectites belonging to their museums.

pitted (coarsely or finely, *5*, *24*, *29*), scaly [1]) (coarsely or finely, *33*, *38*), slaggy (always finely, *9*, *32*) and almost smooth, usually brought about by very broad and shallow scales, bearing small groups of pores and sparse pittings (*3*, *11*, *20*). Without exception the ornamental properties of the background remain the same on the entire surface of the body.

Upon these properties also depends the *lustre* of a body, which is bright as varnish or sealing wax only with scaly surfaces, whereas, on the other hand, slaggy surfaces are nearly dull. A few bodies appear to have been abraded by a continual movement in water (or some other liquid) and, accordingly, are almost lustreless. As far as my experience reaches this case is rare; moreover, specimens only *partly* scoured did not come to my notice; so, possibly, the lustre may have been worn off by another agent or in another way.

The depressed bottoms of navels and gutters on those abraded dull bodies always kept their original lustre. On the other hand, the groove-bottoms on common bodies occasionally display a lesser lustre than the general surface.

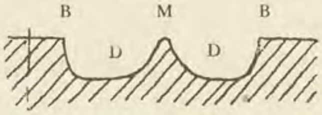
The **navels** (this name was introduced by P. van Dijk in 1879) were termed by Krause „Höfchen", which means the pap and the ring around it. I shall make use of the first mentioned term. The finest specimens of navels are found on the most strongly bent parts of the surface, *e.g.* on the keel-zone (*22*, *23*, *36*) and on the cylinder-endings (*28*, *39*), where, in some instances, they occur in groups or rows up to 5 or 6 pieces. Less perfectly developed and also less abundantly they are met with on the cylindrical surfaces (*2*, *27*), but on the majority of the common ellipsoidal bodies they are very sparse or absent.

An abundance of gutters seems to exclude the navels, and conversely; both ornaments apparently replace each other and may be closely genetically related.

If a gutter cuts a navel from the side — a case not at all rare — then the former perspicuously and without exception is the younger ornament (*27*, *33*).

The various parts of a navel are (Fig. 3) the brim (B), the depression (D) and the mountain (M). The *brim*, as a rule, is sharp, edge-like (*20*, *27*, *37*), but on a slaggy or finely pitted background it is usually rounded off (*24*). With well developed navels the *depression* may

Fig. 3.

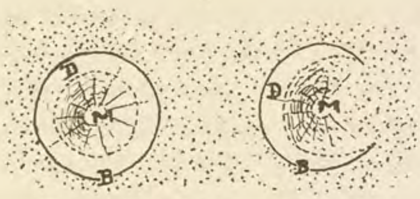


Cross section of an ideal navel.

[1]) This term is not quite right, as the feature does not remind one of *level* scales or tiles, but of the *hollow* tiles of a Dutch roof.

often be circular, Fig. 4[a], (*20*, *28*, *37*); not seldom, however, it is crescent-shaped, Fig. 4[b], the mountain being not isolated but connected with the general surface (*4*, *19*, *36*). The bottom of the depression is smooth, finely pitted or scaly, subject to the condition that smooth bottoms (*36*, *37*, *39*) may be associated with all kinds of backgrounds, whereas pitted or scaly ones are only found with backgrounds of their own kind (*25*, *33*). It is noteworthy that a smooth bottom is not synonymous with an even one.

Fig. 4.



Ground-plan of a navel with *a*. circular, *b*. crescent-shaped depression.

A navel-mountain is never higher than the surrounding surface. If such a *mountain* is very low, it is usually not distinctly separated from the depression, and both together resemble a hilly landscape in miniature. These forms I call *saucers* (*41*, *42*); their bottoms are never smooth, always pitted or scaly.

In most cases, however, the mountains are higher. When they have level tops (*28*[b], *36*[r]), then the latter always lie exactly on the same level with the surrounding surface. Top and surface, in this circumstance, strictly agree with regard to ornamentation; they manifestly belong together. In some instances the space at the top is wholly or partly taken up by a gutter (*21*[r], *36*[m]) and in virtue of its situation one is compelled to believe that the latter is of a later date.

Keen-edged ridges sometimes occur as substitutes for the real mountains. When both ends of such a ridge are still connected with the brim, as is usually the case, the navel is divided into two nearly equal parts (*21*[l], *39*[r], *4*) and there is no distinct depression. However, occasionally one end of the ridge is abruptly cut off by a concavity; obviously the latter is the imprint of a sherd, which parted and loosed the connection. These ridge-bearing navels may be considered as transitional forms from the mountain-bearing navels to the saucers.

Thumb-nail marks (*9*, *24*) are the incipient stages of navels. They exclusively occur with a slaggy or finely pitted background, and exhibit rounded-off brims; moreover the crescent-shaped depressions agree in ornamentation with the surrounding backgrounds.

Krause mentioned faintly marked, somewhat elevated lines, radiating from the mountains. They are, indeed, present on nearly all the navels of my collection, and they are often rather conspicuous and keen (*19*, *26*). They originate at the top or the flank, and either run forth as far as the brim (*26*) or vanish somewhere in the depression. It is hardly possible to explain these lines otherwise than representing intersections of the imprints of small sherds, which cracked off from the main body (*26*, *28*). This assertion is by no means improbable, since there are many instances of indisputable imprints of sherds at the surface of the Billitonites; one of these instances was already mentioned. The mountain tops in *26* and *39* are truncated by sherds, and the saucers *41*, *42* are very fine objects of study in this respect.

The **gutters**. Just as well as many Billitonites do not carry navels, so on many others, especially among the smaller bodies, no traces of gutters are perceptible. It evidently follows that, though navels and gutters are very characteristic features of the Billitonites, they are nevertheless not essential. In contradistinction to such gutterless bodies, there are others with such a profuse development of gutters that scarcely any room is left to the background.

A cursory glance over a large collection of Billitonites will do to reveal the marked difference often existing between two opposite parts of many bodies, with regard to the number of the gutters or to their properties, and this difference is not merely prominent on bodies bearing a keel or keel-zone. Now one side is full of gutters, whereas the other is plain or decorated in quite another manner. At times the gutters are here long and deep, there short and shallow; at other times they are here broad, there narrow (*13* and *16*). Generally speaking, neither the distribution of the gutters, nor their mode of occurrence are equal on the entire surface of a Billitonite, even if its form is very regular.

On normally shaped bodies no rule can be discovered concerning the direction of the gutters, though in places there may be a more or less strong predilection in favour of a special trend, or a disposition to form groups with a rudely radial arrangement (*11*). Only once I saw a large group of gutters radiating in a rather perfect manner (*13*). Some short gutters are occasionally running at right angles to the keel-zone (*10*). But, apart from these special cases, only on the more elongated bodies the gutters display a distinct preference to a single direction, perpendicular to the longest dimension (*1*, *3*).

It seldom occurs that the somewhat longer gutters keep their initial course. As a rule they are anfractuous and composed of some distinct but discontinuous parts, causing gentle or sharp curves (*3*, *11*), Straight gutters are as rare as regularly curved ones (*9*).

When two gutters intersect (*1*, *2*, *11*) their depths are usually unequal and in some cases their bottoms are dissimilarly ornamented too, hence they are likely to be considered as of a different age. But I never observed the gutters running in one direction being all younger than those following another course.

The gutter-bottoms are smooth (*3*, *11*, *27*), pitted (*16*) or scaly (*33*); the brims are keen-edged (*1*, *3*, *11*) or rounded off (*32*). The conditions are the same as those of the navel-depressions, and this accordance also points to a similarity in generation of the two ornaments.

The cross sections of the gutters deserve special attention. The ratio between depth and breadth is not constant; on the contrary, both dimensions are variable enough and appear to be independent of the shape or compass of the body. Rather narrow and shallow gutters prevail (*1*, *3*, *11*) and usually the breadth of their basin-shaped section is about twice the depth. With the deeper but still narrow gutters the cross section assumes the shape of a **U** (*3^l^*) and of the much rarer deepest gutters often one of the walls is overhanging (*18d*). Moreover, very broad gutters are met with which are either shallow (*16*) or deep (*7*, *10*); the latter almost exclusively appear close to the tapered ends of the pear-shaped bodies (*3*, *5*).

Striae and Grooves. One ought to be permitted to refer to the minute descriptions of those ornaments as seen on the Moldavites, given by Fr. Suess (**14**). However, since this author studied and described every body individually and, consequently, the sentences related to the subject are scattered on various pages, it might take the reader much trouble to find them. So I will save him this, and briefly summarize my own experience, in the same time adding a few more observations, especially concerning the Billitonites.

Striae and grooves are only different names for the same feature. The grooves are visible *and* tangible; they occupy distinct zones or belts on many bodies, but may also be absent. The striae are hardly tangible and often very hard to discern, but *they are omnipresent.* In their own direction striae and grooves not seldom gradually pass into one another; at right angles to that direction the transition is usually very abrupt.

The grooves may vary from fine to coarse, but as a marked difference with the gutters their cross sections are angular and assume the shape of an **L** or a **V** (*5*, *17*, *34*, *35*).

Grooving manifests itself in various ways, *viz.* **a.** rectilinear, notably on elongated bodies (*1*, *3*, *5*, *7*); **b.** more or less curved or corrugated (*17*, *29*), very frequent, especially on the larger isometric bodies; **c.** wrinkled, contorted or crinkled in a peculiar fashion; either, rarely, over the entire surface, or, pretty often, over part of it (*30*, *31*, *34*, and the upper half of *15*); **d.** in zigzag-lines (the lower half of *15*), very rare.

On the button-shaped Australites series of *circular grooves* occur, and Krause published a photo of a Billitonite (Fig. 10 of his paper) also displaying the same feature. In virtue of the meteoritic theory, the rapid turning of the superficially molten body around its longitudinal axis was hold responsible for their existence. In the sequel of the present paper (Part III) I intend to elucidate my conception that the Billitonites are built up by a great many thin layers or laminae. When these are still undisturbed, any section but one parallel to the strike of the layers will show a series of parallel straight lines (the rectilinear striae and grooves). When, however, out of the original mass a sphere or an ellipsoid is cut, the traces of the bedding planes will likewise be parallel, but they will form circles or ellipses (*5, 29, 35*). Finally, when the laminae have been previously disturbed (curved, folded, twisted, contorted, crinkled etc.) then any section must obviously show more or less irregular lines.

The intensity of the disturbance pretty often changes abruptly within short distances on the same body (*15, 31*). It may be inferred from this that the disturbance itself cannot possibly be the result of external pressure, but must have been brought about by internal forces.

The outcome of microscopic examination is not in disagreement with my conception alluded to above. Fr. Suess thinks another interpretation of the feature to be more reliable; he writes: "the striation is the expression of a fluxion structure in the vitreous mass". However, in the first place such a structure is indisputably incompatible with a homogeneous glass such as that of the Billitonites. Besides, when comparing a thin slice of a Billitonite with one of an obsidian, it becomes at once clear that the fluxion structure of the latter and the striation of the former are quite different things.

Grooving is often very conspicuous in gutters and navels, and not seldom it runs in a straight course right across a number of these ornaments (*1, 3, 10, 36, 39, 40*), whereas in their immediate vicinity grooves may be absent. This strange feature may be explained in the following way. Suppose the laminae are inclined to the surface, but scarcely show their traces, as is so often the case. Then a gutter, when coming into existence, does not encounter a physically homogeneous mass, but will have to overcome the resistance of a series of laminae, which need not be wholly identical and are moreover separated by a thin, but probably very tough film. Hence the bottom of the rent will not become even, but costate, and the form of the angular cross-sections of the grooves will depend upon the inclination of the laminae (Fig. 5) **V**-shaped grooves being associated with high dips (*a*), and L-shaped ones with low dips (*b*). With a very small inclination (*c*) the groove-bottom will be even as far as the rent remains in the same layer, which may be a pretty long distance; in passing on to the contiguous layer, a low and small cross-bar may be formed, but obviously there is no necessity for the rent to follow strictly the same course in all the layers which are successively torn open.

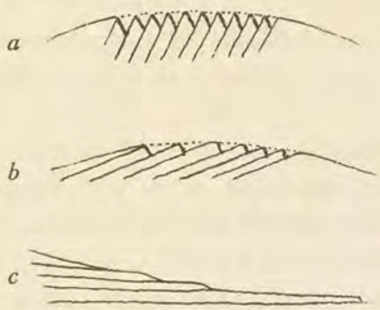


Fig. 5.

The preceding reasoning, therefore, accounts as well for the existence of the grooves and their properties as for the rareness of straight running long gutters.

The **funnels**. "Further ornaments of the surface are apertures of an acute conical form, usually intruding the body in a slanting direction, and which are sometimes filled up by a yellowish perlitic [1]) substance". (Krause, **6**. p. 242). I call them funnels, though their sections with the surface are as a rule oval or elliptic. The acute lower end, resembling a cornet, is very characteristic. Their depth never surpasses 3 mm. but is usually much less.

In many instances they are stuffed with a fine, tough, yellowish, clayey-sandy substance, carrying some small but distinct particles of quartz. This stuffing strongly adheres to the sides and is hard to remove completely. It is worthy of remark that the other ornaments are never filled up in a similar manner, not even when they are deep.

On my Billitonites the funnels are very numerous, and after elaborate examination and correlation the conclusion was reached that most of them stand in close relation to the grooves, and that their number increases with the intensity of the disturbance of the laminae. With a crinkling of the latter a rough and pumice-like surface is always coexisting (*15*, *30*, *31*, *34*). Here and there the features, observed at the sharp turns of a groove-belt, recall the drawings of the well-known saddle-reefs at Bendigo.

A shallow L or V-shaped groove often abruptly deepens at one end into a funnel (*30*, *34*) and in places a row of deep funnels, separated by short interspaces, make up the greater part of a groove (*5*, *17*, *31*). These features exemplify the relation referred to above,

[1]) The term "pelitic" = clayey would have been more in agreement with the real circumstances.

but it must be stated that there also exist isolated funnels showing no visible connection to grooves.

The sides of the funnels, as well as the bottoms of the grooves, are always smooth, with at most a few pittings to break the monotony.

The **pores, pittings** and **cups**. I call *pores* the very smallest, *pittings* the somewhat more spacious hemispherical holes with keen-edged brims which, usually in abundance, occur on the surface of all the bodies, and hence ought to be considered essential ornaments. Some bodies are all over covered with such pittings (*24*). A slaggy background consists of innumerable pores and pits in a particular combination and so closely aggregated as to present no perfect forms (*9*, *32*). On a so-called smooth background they are more irregularly distributed (*11*) and even in the scales the often nearly imperceptible pores (seldom pits) are never lacking.

They are merely superficial features. The interior of the Billitonites is compact and never in the least vesicular; this is clearly revealed on the fractured surfaces of many bodies, caused by recent damages. Besides, they are at a time the oldest and the youngest among the ornaments. Some of them existed prior to gutters and navels, for they are cut by them. Many, however, occur in the bottoms and sides of all the larger ornaments, *cups* included.

The latter are the largests among those hollow hemispheres (*10*). Their number is always restricted and very often they are absent. Their sides are usually smooth, seldom scaled or grooved.

The **splinters** and **sherds**. Apart from the ornaments dealt with, common concavities are visible on the bulk of the Billitonites in a more or less considerable number, and in many instances they are indisputably brought about by splinters or sherds cracked off in one of the latest building stages of the tectites. If they are grooved, as occasionally occurs, they bear a strong resemblance to imprints of shells. When describing the navels I already drew attention to the existence of these sherds, but they are also found scattered over the most various parts of the bodies, and without any regularity as to their distribution. A few Billitonites have their surfaces almost entirely covered by such concavities; they remind one of a turbulent lake on which the waves have all of a sudden been stiffened.

It looks as if the cracking off of the sherds be the result of an excess of strain, and in this connection I must point out once more that they so often parted from the navel mountains. If the assumption is correct, then the latter ornaments must have been in a very particular state of tension.

After a glance at *38*, with its beautiful scaly background, it may appear probable that the surface of this body was originally simply striated and that, subsequently, between the boundary lines of each lamina, an uninterrupted row of minute sherds was cracked off. As for me, I do not object to the supposition of the other scaly surfaces having been formed alike, and this may also account for the absence of larger pits on this kind of background: they, too, formerly existed there but their upper parts were destroyed by the sherds, only the bottom parts, the pores, remained.

The **fragments**. The complete bodies having been amply dealt with, the discussion of the fragments may be limited to some general remarks.

There are *real* fragments and *pseudo* fragments.

The latter are very singular in appearance (*7*, *8*^{a}, *8*^{b}, *12*, *18*) but they do not, as the former, constitute parts of a much larger body, broken asunder. Their fantastic forms may have been brought about by the parting of an anomalously large number of sherds and splinters, in an irregular fashion. All the pseudo fragments which came to my notice and had their places of origin ascertained, had been collected within a narrowly bounded area, but this fact may be purely accidental, owing to the greater attention of the miners or to a somewhat more abundant occurrence.

As far as the mother-bodies of the real fragments could be determined, they always were ellipsoids. A very important feature is that the fractured surfaces never carry any navel, gutter or funnel, but apart from this negative property they differ in no way from the backgrounds of the remaining primary surfaces; their ornamentation, however, is slightly fainter. By this rule the natural fractured surfaces are easily distinguishable from the flat conchoidal surfaces which arose from the recently inflicted damages, which never show any ornament at all but for a few nearly concentric curves, the same as appear when a piece of hard pitch is broken (*35*, middle).

It is therefore evident that the mother-bodies have burst after the formation of the chief ornaments and before the sculpture of the background was completed. And it seems incontestable that the latter must have been independent of the properties of the main body as a whole, and of the movements to which it is usually believed to have been exposed.

On the fractured surfaces, and especially on one or more edges (*6*) a noticeable feature is the occurrence of "composite cups", *i.e.* groups of cups and larger pits of various dimensions, wholly or partly sunk the one into the other, the compound, consequently, acquiring a not insignificant depth. They can hardly be thought of as having served another purpose than as receptacles for gases, and therefore I term them **vacuoles**. The supposition being correct, the bodies have presumably burst because the accumulated gases acquired explosive force. Occasionally long cylindrical holes are met with, now broken up (*6*), which do not appear to have been connected with the surface, and probably were vacuoles too. The sides of all these cavities are always perfectly smooth.

Very interesting is the almost doubtless existence of *hollow* Billitonites, as appears from two fragments in my collection with large concave smooth surfaces, studded with small pits, and which have already been dealt with (*14*).

PART III.

A NEW HYPOTHESIS CONCERNING THE ORIGIN OF THE TECTITES.

Reviewing the statements given in Part I, we may safely postulate that the properties of the vitreous volcanic rocks and those of the glassy tectites do not point to a community of origin. They show neither a similarity of behaviour nor an agreement in composition.

The surface of obsidians, pitchstones and the like is usually smooth; that of the bulk of the tectites is pitted.

The volcanic glass seems to be in a metastable state: the formerly deferred crystallization is nowadays going on (devitrification). In the tectitic glass no trace can be observed of the rows of crystallites which make up such conspicuous figures in the obsidian slices.

Very few glassy igneous rocks are void of cavities and these are often stretched in the direction of flow; even scoriaceous textures are not uncommon. None of these features are met with in the principal groups of tectites.

These cavities have been generated by the expansion of the occluded gases immediately before the period of rapid cooling. Their absence from the tectites therefore indicates a dissimilar mode of occurrence of the gases and a different mode of solidification of the bodies.

The pitted and slaggy surfaces of the tectites can, however, hardly be explained otherwise than as being the visible results of the escape of vapours or gases. And since the interior of the mass has a perfectly close texture, I think that the escape was quiet and that the gases were liberated under the command of a very low pressure. This is in contradistinction to the volatile constituents of the volcanic glasses, which are expelled in a turbulent manner under high pressure.

In both cases accumulation of gases in an almost solid body is imaginable, and if they cannot escape in a natural way their tensional power may at last become strong enough to cause the body to burst. The débris of an obsidian change no more then, they are dead-like. Those of a tectite, on the contrary, are still living, they continue to give off gases, as is conclusively proved by the pits on the fractured surfaces (p. 23).

In virtue of these evidences, I venture to say that a hypothesis inferring the origin of the tectites from the cooling of a molten mass, cannot reasonably be thought of. With the small bodies dealt with here, this process cannot possibly have taken place slowly enough to account for the low pressure of the gases.

Such a state of affairs can, I think, only be brought about in a colloidal mass, out of which the moisture escaped by diffusion and evaporated at the surface; the mass itself gradually dried up and ultimately vitrified.

If I am right in this respect, then the origin of the tectites would have been once more transferred to the earth, from which it was withdrawn in a moment of despair, but to which it logically belongs. It would then also be more in consonance with that origin to speak of *xeroliths* in stead of *tectites*.

We have at first to inquire: How can we account for the generation, in quite a natural way, of a colloid possessing a chemical constitution approximating that of the tectites, *i.e.* a siliceous sol mixed with sols of various oxides or hydroxides and also containing alkalies? In my opinion this substance might come into existence in the following way.

Suppose such a large quantity of humus be generated in a certain area that, after its partial decomposition by bacteria, a considerable rest is left in which all the available alkalies of the decayed subsoil can be taken up, without the solution becoming saturated with them. Such an *unsaturated humus* which, as is well-known, when mixed with water forms a humussol, in this condition further reacts upon many kinds of inorganic compounds, especially those of silica, alumina and iron, with the effect that their colloidal solutions are carried off by the humussol.

If this particular kind of dissolution acts upon a *weathered magmatic rock*, a composite inorganic sol will be generated containing silica, iron, alumina, alkalies, lime and magnesia, which gets mixed with the organic humussol. The chemical constitution of the former will depend upon the nature of the rock, the degree of saturation of the humussol, and perhaps on still other unknown factors.

There will be no special reason for variability, worth mentioning, in the composition of the sol within a limited area, provided the petrographic circumstances remain the same (*e.g.* the Billitonites).

If, however, a vast area is to be taken into account, it may occur that the same petrographic collective name is to be assigned to the preponderating magmatic rock (*e.g.* granite) but that nevertheless its special properties vary with the provinces or districts embraced by that area. Moreover, the external, chiefly climatic circumstances cannot be equable on a vast territory. Hence, even if the humus be in excess over the whole extension, and if the solutions generated be of the same general kind so as to produce one single group of glasses, the chemical and physical properties of the latter may also vary with the said districts or provinces. This apparently did happen in Australia (**17**) and in Bohemia-Moravia (**14**).

Of course the difference will be much greater, if various kinds of rock are exposed to the dissolving action of the humussol (Australites and Queenstownites in Tasmania).

The organic sol, acting in the manner described on the weathered products of a granite or cognate rock (arkoses included), will most certainly generate a colloidal solution of a pronounced acid character (from silica). And since granite, gneiss, micaschists and the like are prevailing in all the areas in which the tectites abound, the chemical constitution of the latter is readily explained.

Generally, inorganic colloids are unstable and irreversible; in the presence of an electrolyte they already coagulate when only slightly concentrated. In the case in view, however, dealing with siliceous sols and with the humussol acting as a protecting colloid, no theoretical objection can be raised against a much higher concentration. Furthermore, as long as a coagulum of this composition remains moist, the coagulation is reversible: under this condition liquid can again be absorbed, causing a swelling of the mass. This property is not lost until the moisture has been completely given off.

There was not, I think, an excess of humussol continuously; its quantity probably depended on the season. In the lesser part of the year the colloidal solution in question may have been generated rather copiously; it flowed down to suitable spots, where it stagnated, was exposed to heat and air, evaporated, got concentrated, finally coagulated and dried to a certain extent, before next year's supply arrived. Each thin annual layer got in this way distinctly separated from its predecessor, with stratification (foliation or lamination) of the gel as the outcome. This special feature is analogous to the common geological stratification in so far, as both came into being by breaks in the supply of matter. In the former, however, the layers were all of the same kind, possessed the same physical and chemical properties. Hence in very thin slices the appearance will be the same over all, whereas thicker slices, looked at in a suitable position with oblique illumination, may show a faint cloudy indication of bedding planes.

Of course some favourable circumstances must coexist in order to have the solution and its final stage, the coagulum, preserved, and apparently the presence of an impermeable honeycombed surface is one of them. Such surfaces are often met with in areas in which the subsoil is a decayed granite.

Though the colloidal solutions very likely did not cover long distances, they need not settle on exactly the same rock as the one they came from. Hence in Billiton the tectites are occasionally found lying on weathered slates, though they originated from granites.

As stated above two processes, producing opposite effects, alternated in the coagulum. In the dry season the moisture diffused to the top layers as the only ones that were exposed to the air, and it evaporated; consequently the volume of the gel was reduced. In the wet period the gel was allowed to absorb liquid and to swell. However, since the first process lasted longer and was probably more intense, the final stage was a thoroughly dried up and even vitrified matter.

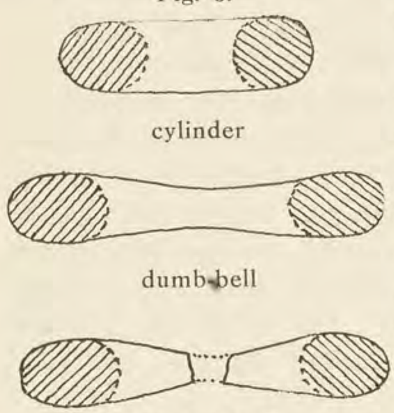
The vitrifying of the stuff was attended by the generating of cracks similar to those occurring in the perlites. And for a long time already Cole (and also Lévy & Fouqué) proved that this feature can artificially be called up in some kinds of colloids. From these experiments Judd inferred (**5**) that the real cause of the said cracks might be the contraction which is causally related to the slow escape of the volatile substances formerly bound up in the gel. I emphasize the word "slow", for the slight velocity of escape is supposed to have a most important bearing on the genesis of the cracks.

It is well-known that the phenomenon is adherent to the more acid igneous rocks and, besides, it can hardly be denied that the moisture absorbed by the gel separated very slowly from that matter. Therefore, though no definite proof can as yet be afforded, I suggest that, merely as a consequence of the almost imperceptible transition from the weak to the solid state, a kind of perlitic cracking was brought about, which feature gave rise to a subsequent disintegration.

Whether the bodies generated by the latter change will show a more or less perfect shape, is likely to depend on the degree of perfection of the cracking, which in itself seems to be closely bound up with the acidity of the gel. The Billitonites and Australites are by far the best shaped among the tectites and their silica content (from 70 to 77 per cent) is remarkably in accordance with that of the perlites. With a higher acidity the perfectness of shape is rapidly lessened; the bulk of the Moldavites (from 77 to 83 per cent of silica) assume but the form of a sherd, and the configuration of the Queenstownites is very singular but by no means regular.

Concretion, as is the case with flint, is out of the question, nor can any radiate disposition be detected in the matter.

Fig. 6.



It will be easily conceived that the bulk of the spheroidal bodies will be made up of ellipsoids, and that a real sphere will be brought forth only exceptionally. Local conditions may give rise to aberrant forms, and the accompanying drawings (Fig. 6) express my ideas as to the manner in which cylinders, dumb-bells, pears and tears, are related to ellipsoids. All the pear-and-tear shaped bodies of my collection have their tapered ends truncated, and nearly all of them exhibit very deep gutters close to these ends (*3, 5, 29*), so there is every evidence of the latter being broken off.

The incipient stage of the perlitic cracking coincided with an advanced stage of dryness, and just as well as the cracks were formed as a consequence of desiccation, so the latter was promoted by further enlargement of the cracks. At last the coherence was completely destroyed and a nest of bodies made their appearance of various sizes and shapes but, as a rule, all small ones. The interstices between the ellipsoids were taken up by irregularly shaped masses. These may frequently have been crumbled to such a degree as to be lost afterwards; in a better preserved state they are supposed to have yielded the *pseudo fragments*.

As long as the gel-lump was still sound, the diffusion could proceed to the top parts only, but from the moment the cracks appeared, it could take more directions at a time, though probably not with equal intensity. Often the desiccation of the outer parts may have been in advance of that of the interior; then the outer film at last rent from too much tightness (*gutters*). If, however, the more dried parts were pretty even and bounded by curved surfaces, the strain at the outset didn't cause rents in the former, but it tore small hemicircular furrows in the latter (*navels*). Evidently, an irregular distribution of the gutters must have been the rule under the circumstances described, and it is a matter of experience that the spots, showing a maximum and a minimum development of those ornaments often take up an opposite situation.

The amount of swelling in the various parts of a body must have depended upon their degree of desiccation. When the latter, in special cases, had been uniform throughout, the swelling could be uniform too, and the laminae kept their parallelism (*the rectilinear striae and grooves*). However, these were exceptional events; it follows from the manner in which the desiccation was brought about that it was usually unequal. The first time that swelling afterwards took place, this could not be equal either; consequently the layers got disturbed in one way or another. The next desiccation was unable to re-establish the primitive state; the next swelling made the contrast still more striking, and so on. This process may perhaps be compared with the autoplastic movements of the salt layers, according to LACHMANN's theory.

In this mass which, for the rest, was chemically well-nigh homogeneous, the perlitic cracks arose independently of the disturbances, and the laminae were cut in all possible directions by the spheroidal surfaces pertaining to the cracks. This state of affairs must have facilitated the further escape of moisture, for this was often allowed to take advantage of the bedding planes, which acted as planes of least resistance. Close to the surface these planes gave a little way here and there in order to let the bubbles pass; the *funnels* remained open, for the continually increasing viscosity prevented their being shut. At the sharp turns the lesser coherence of the layers may have caused an abundance of funnels in these very spots.

In the middle-sized and small bodies the centre was probably the first to dry and to vitrify; the glass furtheron enlarged in a somewhat concentric manner. In the larger-sized bodies, however, the transformation proceeded sometimes from more than one centre, so it could happen that the moisture was prevented from escaping out of a part of the interior. The gases generated were then compelled to gather in one or more selfmade *vacuoles* and if their tensional force surpassed the resistance of the body, the latter was caused to burst asunder.

The outer films of the bodies may have kept their moisture longest, but the minute bubbles formed in the very last period of desiccation were for themselves unable to overcome the surface tension. They gathered in small groups, at the same time raising a little the outermost film, until the joint efforts of such groups succeeded in bursting it; in this way *pits* and *pores* made their appearance.

A transmutation into the vitreous state being always attended with strain, the cracking off of small *sherds* and *splinters* is not at all surprising and only a natural consequence of that property.

I have purposely dealt with the details somewhat elaborately in order to prove that they, individually, can readily be explained without the assistance of extraordinary forces or circumstances. Though amplifications and improvements may be introduced, these will probably not derogate from the main points of my supposition, which has at least a reason of existence equal to the hypotheses propounded as yet.

I regret very much having no opportunity to carry out the necessary experiments with colloids of similar composition, so I must leave it to others to take over this business.

In conclusion I should like to make the following remarks.

I. The peculiar colours characterizing the bulk of the tectites, as well as the high content of carbon monoxide and carbon dioxide in the gases evolved (experiments of Brun, p. 13) may be attributed to an admixture of humic acid in the bodies.

II. The action of humic acid can likewise affect more basic rocks, and the colloids generated will then be richer in iron and poorer in silica, consequently their specific gravity will be greater (Schonite ?). Possibly, the general aspect of these bodies is not of a kind to attract special attention.

III. It appears as if the percolating of the weathered products by humic acid, generating tectites, and the one by common rain water carrying carbonic acid, generating lateritic rocks, cannot occur in the same area simultaneously.

IV. Presumably, the highly acid Queenstownites are the products of the humic acid having acted on arkoses. In this connection I will quote a remarkable verdict of the late Fr. Berwerth: "After having pointed out the similarity of the chemical composition of the tectites with that of the bed-rocks on wich they are found, I have the strong conviction of the former being made of material belonging to the latter". On the strength of the views stated in the present paper I join that opinion to the very letter, but concerning the manner in which the manufacture was supposed to be achieved, our ideas differ considerably.

V. In my supposition cooling and supercooling of the matter are out of the question. Two facts harmonize with this conception, *i.e.* the lack of any trace of devitrification and the result of Bareš's experiments (p. 9).

VI. The keel of many Billitonites, the frequency of flattened sides, and also the button-shape of many Australites are sufficiently explained by the mutual pressure exerted by the nest-bodies in the periods of swelling. The strange feature of the button-ring (Fig. 2 p. 15) being sometimes only in part existing, or having been found completely pinched off, is also freed of its queerness when this pressure is taken into account. Since the larger cups are almost restricted to the low-shaped bodies (*10*) which may have assumed their aberrant form by the strong pressure to which they were subjected, it appears probable that the former are mere squeezed out vacuoles.

VII. The genesis of the tectites is most likely causally related to special climatic conditions. This accounts for the occurrence of the Queenstownites and Moldavites at definite altitudes and perhaps also for the existence of Billitonites in the island of Billiton and their absence in the neighbouring tin-bearing islands of Banka and Singkep.

It was already stated on p. 26 that the climate in a vast territory can hardly be equable, so the conditions under which the tectites were allowed to generate may have existed at various heights in different parts of the area. It is in consonance with this conception that the Australites are not found in narrowly limited altitudes as is the case with the other groups.

Since in the countries now famous for their tectites no indication is known to exist that these bodies are still generated now, the inference may be drawn that a change in the climate must have occurred since the late-Tertiary. As regards the Malay Archipelago I already arrived at this conclusion in one of my former papers (**20**); R. Lang (**7**) is of the same opinion.

In two recent papers [1]) I put forward an altogether new theory

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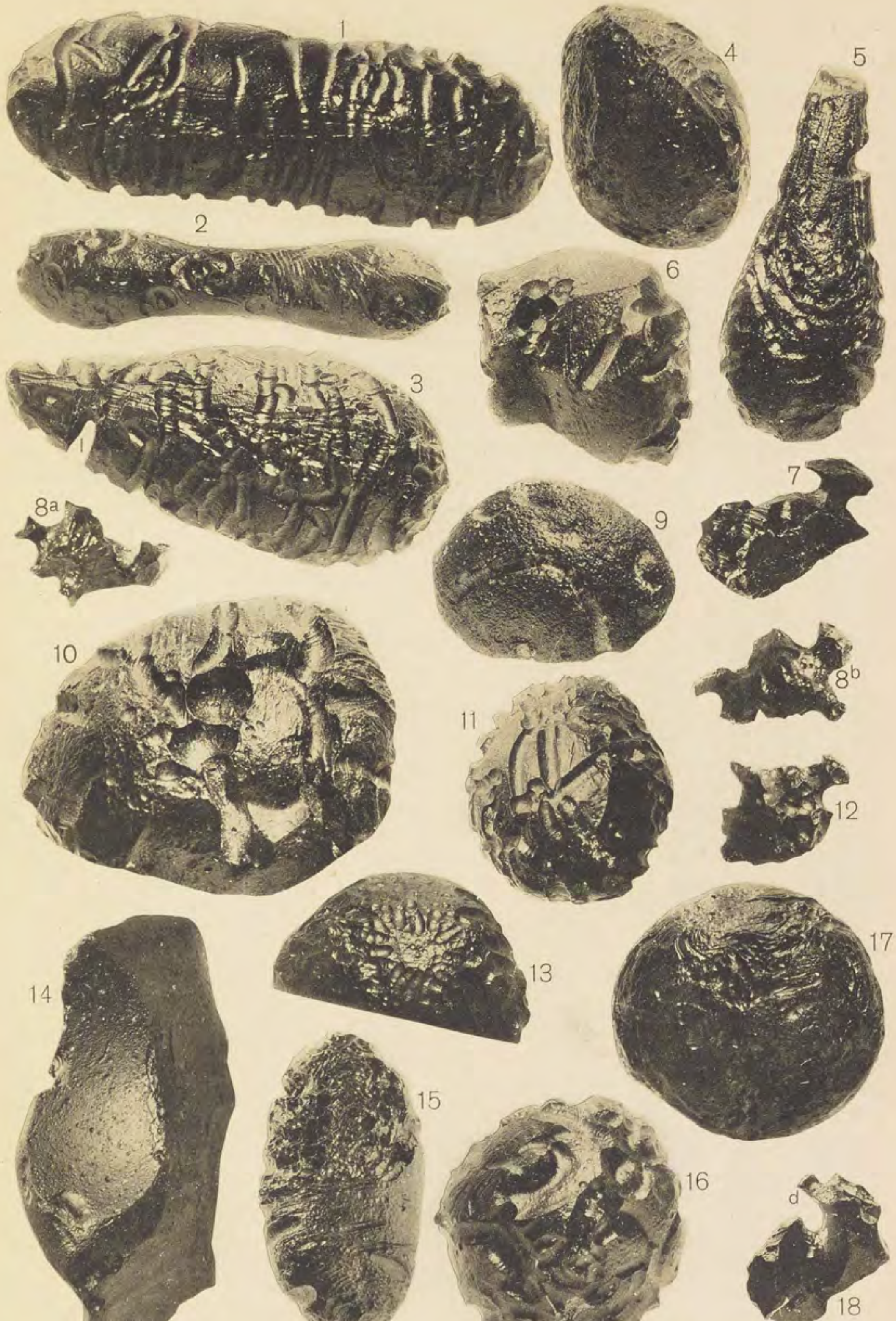
[1]) 1. The Genesis of the Malay Archipelago looked at in the light of Wegener's Hypotheses; in: Tijdschrift Kon. Ned. Aardr. Gen. Juli 1921, p. 484—512 (in Dutch idiom).

2. On some Extensions of Wegener's Hypotheses and their Bearing upon the Meaning of the Terms Geosynclines and Isostasy; in: Geol. Serie der Verhandelingen v. h. Geol. Mijnbk. Gen. v. Ned. en Kol. Juli 1921, p. 113—133 (in English idiom).

regarding the manner in which the continents and islands came into their present locations. This theory also accounts for the climatic changes in the course of the earth's history, as well as for the possibility of the Sunda islands having been quite differently grouped in Tertiary times than they are now.

VIII. The current opinion admits the relative rareness of tectites; this feature is probably only seeming. Up to now they have been nearly always discovered by the intermediation of agriculture (Moldavites) or of mining (Billitonites, Australites); there may, however, be many other areas where they abound, without their existence having come to our notice.



HELIOTYPE, VAN LEER, AMSTERDAM

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