1. *Anatase in the Trias of the Midlands of England.* 2. *A peculiar occurrence of Magnetite in the Upper Bunter Sands.*

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1. *Anatase in the Trias of the Midlands of England.*

THE mode of occurrence and origin of the various forms of titanium dioxide as rock constituents have received attention at the hands of many petrologists, both on the continent and in our own country. Among the works of the former dealing with this subject, Thürach's exhaustive treatise[1] on microscopic rock-forming rutile, anatase, and brookite, is undoubtedly the most important : in England, Mr. Maynard Hutchings has described in great detail the occurrence of rutile and anatase both as constituents of clays and slates[2], and as a product of contact metamorphism in the Lower Coniston Flags[3] in the neighbourhood of the Shap granite; Mr. J. J. H. Teall has also described rutile needles and anatase crystals from clays of various ages[4], and anatase from the Cleveland iron-ore[5]; Mr. Allan Dick[6] has mentioned the occurrence of rutile in the Bagshot Sands; and Mr. H. H. Thomas[7] has lately described these minerals from the Budleigh Salterton Pebble-bed of Devonshire.

I have been for some time engaged in examining the mineral constitution of the Triassic sandstones of the Midlands, and have found that of the heavier minerals, that is, those exceeding a specific gravity of 2·8, anatase, both by reason of its abundance and its mode of occurrence, is the most interesting, so much so that although Thürach has already

[1] 'Über das Vorkommen mikroskopischer Zirkone und Titan-Mineralien in den Gesteinen.' Verh. physik.-medic. Ges. Würzburg, 1884, N. F. vol. xviii, No. 10, pp. 1–82.

[2] Geol. Mag., 1890, p. 264.

[3] Quart. Journ. Geol. Soc., 1891, vol. xlvii, p. 318; Geol. Mag., 1891, pp. 459, 528.

[4] Min. Mag., 1887, vol. vii, p. 201.

[5] 'British Petrography,' 1888, pl. 44, fig. 6.

[6] Nature, 1887, vol. xxvi, p. 91.

[7] Quart. Journ. Geol. Soc., 1902, vol. lviii, p. 620.

called attention to the widespread distribution of this mineral, and has expressed his opinion as to its origin in various rocks, it has been thought worthy of a brief description.

Of a large number of sandstones, few failed to yield more or less anatase; and even where it was not found after a single separation there is no reason to doubt that, judging by the similarity of the associated minerals, a more protracted search would have resulted in success. Although nearly always present, it was found, however, that the ratio of the anatase to the other minerals in the heavy residues was always greater in specimens from the Keuper than in those from the Bunter. The following have been selected as affording the best material for the study of this mineral:—Keuper sandstone from Sutton Coldfield, Storeton in Cheshire, and Weston, also in Cheshire; sandstone from the Bunter Pebble-bed at Dale Abbey, near Derby, and Bunter sandstone from Kingswinford, near Stourbridge.

The anatase crystals vary considerably in size. The smallest that have been measured are 0·025 mm. in greatest diameter; the majority average 0·06 mm.; while a few, especially those with the octahedral faces well developed, reach 0·17 mm. As far as can be ascertained the individuals are composed entirely of the forms {111} and {001}, the extent of development of the latter determining the pyramidal or tabular habit of the crystal. Perfect pyramids, however, with the basal plane completely suppressed, have not been seen. The crystals are generally colourless; but some exceptions have been seen in the specimens from Dale Abbey, where a violet-brown and a yellow crystal were found. Similarly, the crystals are generally perfectly clear, a feature which is partially masked in those with a pronounced pyramidal habit by the strong total reflection; but some, especially among the larger tabular crystals, are encrusted with a granular substance which is white by reflected light. In convergent light, all the crystals were found to be abnormally biaxial, the uniaxial cross opening slightly into hyperbolae on rotation.

Detached crystals occur in these sandstones, but it was noticed that these are very rarely perfect, some flaw being nearly always evident. On the other hand, clusters of minute crystals are frequently met with, and also larger crystals, with a perfectly sharp outline, projecting from the surface of grains of a white substance, sometimes tinged with yellow, red, or brown, which there is every reason to suppose is leucoxene. In support of this view, which it is impossible to prove by chemical methods in the presence of a known titaniferous mineral, it may be mentioned that the nucleus of these white masses has often been found to be an opaque black mineral, similar to the cores of ilmenite in masses of leucoxene in igneous rocks. The cleavages parallel to (111) and (001) are rarely evident.

If, like the minerals with which it occurs, namely, zircon, rutile, tourmaline, staurolite, &c., the anatase is of detrital origin, there are two difficulties to be accounted for. First, how is it that the cleavages, which are described as perfect, are not better developed? and again, how is it that the crystals, which are softer than rutile, zircon, or tourmaline, present so sharp an outline, while the last-named minerals are, with few exceptions, distinctly worn? For the sake of comparison, a specimen of anatase from the altered Lower Coniston Flags was examined, with the result that there appeared to be no possibility of the crystals in the sandstones having been derived from such a source, the disparity of size (those in the altered flags being very minute) and the prevalence of the pyramidal habit being fatal objections; nor is there known to be any source within reasonable distance where larger crystals could be derived, such as those mentioned by Thürach as occurring in the granite of Striegau.

That these anatase crystals in the sandstone had been formed after the deposition of the sand, suggested itself early in these investigations; but when undoubted anatase crystals were found completely enclosed in quartz this view had for the time to be abandoned, and for some time no way out of the difficulty was forthcoming. However, the solution presented itself in the Keuper sandstone from Weston, where a detached crystal of anatase was found with a beautifully doubly-terminated quartz crystal growing on it, measuring not more than 0·07 mm. That this delicate quartz crystal had been formed after the deposition of the sand cannot be doubted: if it had been transported by wind or by water, it could not have failed to have become detached from the anatase. Therefore, although one could believe that some, at least, of the anatase came from a distance, if a reasonable source could be pointed out, a sufficient explanation for these quartz-enveloped clusters is that they have become surrounded by a deposition of secondary silica.

When one considers the purely secondary nature of rock-making anatase, that it never is known to occur in fresh igneous rocks, and how abundant and bewildering are the changes experienced by the titaniferous minerals among themselves, in addition to the above considerations of perfection of outline, rarity of cleavage traces, and the absence of any known available source if of detrital origin, the conclusion cannot be resisted that these anatase crystals have been formed, after the deposition of the sandstone, from leucoxene, which in turn has been derived from other titaniferous minerals, chiefly ilmenite.

There is another possible source of the anatase. Both my friend Mr. Thomas and myself, while working on the Triassic sandstones, were struck by the great scarcity of sphene, which from its widespread occurrence in igneous rocks, might be expected to be abundant. That this may be accounted for by supposing that some of the anatase has been derived from this mineral, either with or without the formation of leucoxene as an intermediary stage, is very probable, seeing that Diller has described anatase after sphene in amphibole-granite and in 'Schalstein[1].'

In these Triassic sandstones, then, we have, first, leucoxene after ilmenite, then anatase after leucoxene, and lastly secondary quartz deposited on the anatase. Why the leucoxene should afford anatase instead of sphene, an alteration common in other rocks, cannot be explained, seeing that the conditions under which the change took place cannot have been far removed from those of ordinary weathering. Were we dealing with contact metamorphism the problem would be comparatively simple; indeed in the case of the re-crystallization of rutile as anatase, described by Mr. Maynard Hutchings[2], and as brookite, described by Beck in the Silurian clays of Saxony[3], the experiments of Hautefeuille can be profitably appealed to; but in this case, where the conditions cannot have been such as Hautefeuille demanded for the artificial formation of rutile, or even those under which the experiments of Daubrée and Deville were conducted, we must accept the phenomenon as an instance of the unaccountable vagaries of titaniferous minerals, whose only conception of order seems to be a tendency towards the form rutile.

In conclusion, I must record my indebtedness to those who have offered me their assistance, especially to Mr. Allan Dick, and to Mr. Maynard Hutchings, who has placed at my disposal his preparations described in the 'Quarterly Journal of the Geological Society' and in the 'Geological Magazine.'

2. *A peculiar occurrence of Magnetite in the Upper Bunter Sands.*

The specimen of Upper Bunter Sands, in which this magnetite occurs, was collected at Hinksford (Staffordshire), near Stourbridge. It is a white, very loosely coherent sand of medium grain; and contains,

[1] Neues Jahrb. Min., 1883, vol. i, pp. 187, 189.
[2] Geol. Mag., 1891, p. 459.
[3] Min. petr. Mitt. (Tschermak), 1893, vol. xiii, p. 290.