Petrology. — *On the recognition of volcanic material in sedimentary rocks by means of heavy mineral investigation.* By C. H. EDELMAN (Communicated by Prof. H. A. BROUWER.)

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In this preliminary paper the question is discussed in how far heavy residues of sedimentary rocks may render the determination of volcanic origin of a rock possible.

For two reasons the question is of some interest. When tuffoid rocks are not or only slightly weathered the determination by means of thin section methods is always possible [1]); if the rocks are strongly decomposed, however, this method is not always sufficient. In this case the investigation of the heavy components, which generally belong to the most resistant minerals, may be of direct importance for the determination of the origin of the rock. A second reason is based on the fact that in modern sedimentary petrology large numbers of heavy residues are prepared for other purposes and that for the application of heavy mineral research it is useful to try this method also with regard to the above mentioned problem.

Heavy mineral slides of tuffoid rocks have only rarely been described before [2]).

An investigation in this direction has been made of a collection of tertiary tuffoid rocks from West-Java, East-Borneo and Poeloe-Laoet and of some recent volcanic ashes from different localities.

The problem has also been considered from a theoretical point of view, while it appeared to be possible to foresay some of the mineralogical features of these volcanic sediments on the base of general petrological knowledge.

1. The question arises in how far in volcanic sediments minerals might occur which are not found in normal detritic rocks. This possibility is excluded à priori, because the detritic material that builds up the sedimentary rocks may be derived from volcanic as well as from other rocks. Guide minerals, the very presence of which may point to volcanic

[1]) L. V. PIRSSON. The microscopical characters of volcanic tuffs. Amer. Journ. of Sc. 1915 pag. 191.

C. S. ROSS. Altered palaeozoic volcanic materials and criteria for their recognition. Bull. Am. Ass. Petr. Geol. 12. pag. 143 (1928).

[2]) C. S. ROSS, H. I. MISER and L. W. STEPHENSON. Water laid volcanic rocks of early Upper Cretaceous age in S. W. Kansas, S. E. Oklahoma and N. E. Texas. U. S. G. S. Prof. Paper 154 F, 1928.

origin don't exist therefore. However, the femic constituents of the volcanic rocks may be considered to be characteristic to a certain degree. These minerals e.g. biotite, some amphiboles and pyroxenes belong to the minerals that are easily to be decomposed and don't stand a long transport. Their presence in detritic rocks is very limited therefore [1]), but volcanic sediments sometimes contain large quantities of these minerals.

When heavy residues show large quantities of femic minerals this feature may be considered as an indication of volcanic origin of the rock ; however, it is no conclusive proof.

2. Among the minerals which are widely distributed in detritic rocks, there are several which cannot occur in volcanic rocks. This is specially evident for minerals which only originate in metamorphic rocks. In sediments of these minerals staurolite, kyanite, andalusite, sillimannite and chloritoid are of frequent occurrence. If these minerals participate in considerable quantities in a heavy residue, it may be considered to be impossible that the rock is of volcanic origin.

The only possibility that might introduce metamorphic minerals in volcanic rocks is the inclusion of metamorphic material by the magma, a circumstance of little quantitative importance in this connection.

This feature is sufficient to exclude a possible volcanic origin in many cases. As a proof of volcanic origin it is not always conclusive, owing to the fact that several detritic sedimentary series are known to contain little if any metamorphic material.

3. A similar feature, but of much wider application, shows the mineral tourmaline. This mineral is genetically bound to conditions which are characteristic for abyssal rocks, metamorphic rocks and pneumatolitic products. A few times it has been described from quartz-porphyries and therefore it is not quite sure that it should not occur in tuffoid rocks. But it is evident that the occurrence of much tourmaline is a strong argument against volcanic origin.

Tourmaline belongs to the minerals which occur in nearly all detritic rocks. The mineral is one of the so called "espèces banales" of CAYEUX and therefore the absence of tourmaline in tuffoid rocks is a striking feature, which can often direct be interpreted as an argument of volcanic origin.

This feature is one of the most useful, derived from heavy mineral research for this purpose.

4. From the above arguments follows that heavy mineral slides of tuffoid rocks are not characterised by a great variety of mineral associations. Besides the femic constituents already mentioned before, only opaque

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[1]) These minerals are strongly affected by certain diagenetic tendencies and are therefore only rarely met with in older sediments. This holds specially good with regard to the pyroxenes.

minerals, zircon, apatite, sphene, anatase, brookite and rutile may play an important part. A reserve has to be made for the minerals garnet and epidote which have been described in numerous extrusive rocks, but have not been found in tuffoid rocks as yet. For that reason these minerals have not been added to the list of possible heavy tuffoid minerals.

The heavy residues of tuffoid rocks are therefore very little complicated. A consequence is the frequent occurrence of exceptional simple slides, which sometimes practically consist of one component.

5. In addition to the above a last and very characteristic feature may be mentioned: the very little variation of properties of each constituent in a special volcanic sediment.

This feature is a consequence of the fact that during the crystallisation of a certain magma the conditions for all centres of crystallisation are about equal and therefore crystals of about the same form, size and chemical composition are formed.

Therefore the presence in a heavy residue of almost identical crystals of one of the scarce components is to be considered as a characteristic of volcanic origin.

This feature leads to a fundamental difference between volcanic and normal detritic sediments. The latter are to be considered as a mixture of a number of primary rocks of which each perhaps shows the uniformity of properties of constituents but which show mutual differences owing to differences in conditions during crystallisation. In the case of tuffoid rocks it is quite the contrary, a feature of much importance for the determination.

This uniformity of properties is especially shown by the zircons. In slides of detrital sediments as well as in tuffoid rocks zircon is one of the most prominent components. In detrital sediments it often shows an almost infinite variation in habitus and degree of rounding; in volcanic rocks, on the contrary, the monotony of properties is quite remarkable.

The other components may show a similar uniformity as the zircons, but owing to the fact that the frequency of occurrence of the other transparent components is only rarely so great as of zircon, their features are less conspicuous.

This uniformity still increases the tendency of volcanic sediments to show exceptionally simple heavy residues.

If a clastic volcanic rock consists of fragments derived from different eruptions, the uniformity of properties may be only little developed. In that case the volcanic origin exhibits itself only in the pure mineralogical characteristics.

On interpreting these features it is very desirable to compare the slides with those of the surrounding non volcanic sediments. Only in that case definite conclusions on this point may be arrived at. This specially applies to the fifth characteristic: the monotony of properties of the components.

These features are confirmed by the results, obtained by the investigation of the collection of tertiary tuffoid rocks from the Dutch East-Indian Archipelago, already mentioned before.

The tertiary detritic rocks of Java and Borneo ordinarily yield heavy residues composed of the "espèces banales" in the sense of CAYEUX. An average composition of heavy residues of East-Borneo tertiary sediments is: Iron-ore 65 %, non opaque minerals 35 %; in relative percentages: Tourmaline 18 %, zircon 73 %, rutile 6 %, garnet 2 %, rare components 1 %. Zircon partly occurs in euhedral crystals of varying habit, partly in rounded or angular fragments.

Interbedded tuffoid rocks show heavy residues with quite different characters. Some of them practically consist of iron-ore, making up 95 % or more of the slides, with scarce crystals of zircon, flakes of biotite and some hypersthene. In other cases residues were obtained that consisted of 95 %—100 % zircon and scarce grains of ore. These zircon slides show high developed uniformity of properties of the zircon. Mostly the zircons are euhedral and pinkish coloured; in one rock the zircon occurs in two types : a yellow and a colourless variety. In none of them tourmaline was found, a striking deviation from the frequent occurrence of tourmaline in the surrounding detritic sediments.

From Poeloe-Laoet may be mentioned a tuffoid rock that contains little zircon but a very high amount of apatite, very monotonous in habit, and frequent pyroxenes. The West-Java rocks that have been investigated as a rule show high amounts of iron-ore and zircon; one of the slides contained a large number of pyramidal anatase crystals, very uniform in habit.

Summarizing, the features of heavy residues of sediments of volcanic origin may be formulated as follows:

1.	Presence, often in great quantities, of femic minerals, amphiboles, pyroxenes a.s.o.	Indication without proving capacity.
2.	Absence of metamorphic minerals	Only rarely conclusive.
3.	Absence of tourmaline	Often conclusive.
4.	Occurrence of exceptional simple slides	———
5.	Uniformity of features	Practically conclusive.

Amsterdam, Geologisch Instituut der Universiteit.