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## CORRESPONDENCE

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### MICROSCOPIC STRUCTURES IN KAOLIN SUBJECTED TO DIRECT SHEAR

(MORGENSTERN, N. R. & TCHALENKO, J. S., *Géotechnique* **17**, No. 4, 309–328)

This Paper and a closely related publication on methodology by the same Authors (1967a) may raise some doubts on the course the Authors have chosen to study relationships between soil fabric and soil mechanical behaviour.

The Authors seem to be unaware of the fact that the idea of using and adapting principles and techniques developed in rock fabric analysis to soil fabric studies in relation to soil mechanical behaviour, has already been discussed by Sander (1939). It has been restated again, simultaneously by Altemüller (1962) and Lafeber (1962), and has been used systematically since then (Fookes, 1965; Fookes and Wilson, 1966; Lafeber, 1965, 1966; Lafeber and Willoughby, 1967; Willoughby, 1967). It is regrettable, therefore, that the Authors have failed to recognize the full consequences of the concept when they categorically state that 'An original fabric will be either random or will display a planar preferred orientation'. There has been ample evidence available for a number of years (e.g. Sander, 1930, 1948; Kubiena, 1948; Pettijohn, 1957; Turner and Weiss, 1963; Brewer, 1964; Lafeber, 1965, 1966) to show that this is an unacceptable simplification for both rocks and soils.

Unfortunately, their assumption has led the Authors to advocate the use of a photometric method for measuring the degree of orientation of clay minerals in thin sections. They seem to be unaware of the fact that this method has been proposed (and used) simultaneously by Wu (1958) for clays and by Martinez (1958) for quartzites. Both Wu and Martinez stressed that the method is only applicable to monomineralic materials with the very simplest orientation patterns. The Authors have restricted themselves in both papers to pure kaolinite, but the title of their first paper 'The optical determination of preferred orientation in clays and its application to the microstructure in consolidated kaolin' implies a much wider applicability of the photometric method, namely to clays in general. It needs hardly be said that strictly monomineralic natural soils or clays with the very simplest possible (i.e. planar) orientation pattern are rare.

In addition, it may be emphasized that the photometric method on its own cannot measure apparent birefringence, a scalar quantity dependent on crystal orientation. It only measures the intensity of the interference colour, that for a standard thickness (0.03 mm) section of kaolinite happens to be white (to the eye). For a similar 0.03 mm section of illite or montmorillonite, however, the interference colour will be yellow, brown or even reddish or bluish. The measured intensities, therefore, also depend among other factors on the colour sensitivity of the measuring device. As the photometric method only integrates light intensity over a certain area, it tends

- (a) to produce, when the light intensity is plotted against the direction in the thin section, generally rather complex graphs. These may be difficult to interpret as a thin section is only a two dimensional sample of a usually complex three dimensional fabric arrangement pattern (see also Martinez, 1965)
- (b) to obscure the presence of minor quantities of the mineral studied with a preferred orientation significantly different from that of the bulk of the material. These may well influence or even control certain initial phases of the deformation. There is evidence of the occurrence of such 'orientation minorities' in several of the photographs presented by the Authors.

Apparent birefringence (actually the retardation) of individual aggregates, however, can be measured by means of a Berek compensator (Schmidt, 1957; Lafeber, 1967).

Unfamiliarity with certain optical phenomena and techniques on the part of the Authors is again suggested by their preoccupation with form birefringence and their attempts to prove that this phenomenon is absent in their material. Form birefringence occurs in two-component systems only under the following conditions:

- (a) one of the components consists of non-equidimensionally developed particles (e.g. platelets or rod-like shapes) that are small compared with the wavelength of the light. The second component (or matrix) is frequently a liquid or similar substance
- (b) the particles, embedded in the matrix, show a strictly preferred orientation pattern, generally of a very simple type
- (c) either of the two components can be optically isotropic or anisotropic
- (d) the refractive index (or indices) of the one component is (are) significantly different from that (or those) of the other component.

It has been shown experimentally (e.g. Ambronn and Frey, 1926) as well as theoretically (Wiener, 1913; Ambronn and Frey, 1926; Wächtler, 1927; Schmidt, 1957) that such a compound system will display birefringence (termed form birefringence) even when the two components themselves are optically isotropic. The refractive indices, and therefore the form birefringence of the system depend on

- (a) the difference(s) between the intrinsic refractive indices of the two components
- (b) the volumetric proportions of the two components in the system.

Consequently, in the present circumstances, form birefringence should be accepted as additional evidence of preferred orientation.

Apart from its irrelevance, the Authors' 'proof' of the absence of form birefringence in their material is meaningless because there is no guarantee that the quoted comparative birefringence figure of 0.007 for kaolinite does not include in itself a contribution (although not very likely) due to form birefringence. Form birefringence can indeed be troublesome (Grim, 1953) during the determination of the absolute values of the refractive indices of clay minerals by means of the immersion method (Milner, 1962). This is irrelevant, however, in the present context. It is finally rather obscure how the Authors justify the elimination of an absorption factor in their 'normalized intensity' measurements (Morgenstern and Tchalenko, 1967).

It is certainly unfortunate that the Authors have put so much effort into attempts to develop the Wu-Martinez photometric method with its built-in, fundamental deficiencies, instead of concentrating on a further development of other proven, more powerful optical techniques (see e.g. Freund, 1957).

The kinematical observations (apart from the use of a modified, sometimes confusing Sander terminology) of the Authors have been preceded, forty years ago, by the classical experiments and observations of Cloos (1928) and Riedel (1929) (see also Skempton, 1966). The similarity between several photographs published by Cloos and by Riedel and those by the Authors is particularly striking. As a result of their experimental arrangement Cloos and Riedel were able to make a clear distinction between tension and shear discontinuities and to follow their development and behaviour continuously while the deformation was in progress. Both Cloos and Riedel mention, for instance, the initiation of tension discontinuities well before the development of shear discontinuities. There is in addition ample geological field evidence for the occurrence of both phenomena (e.g. Balk, 1937). The 'post-mortem' technique used by the Authors ignores this significant distinction.

Furthermore, Cloos and Riedel experimented with very much larger clay samples and

were able therefore to ignore the edge effects for all practical purposes. In the Authors' experiments, however, the edge effects are so pronounced even before peak strength, that it is extremely difficult to imagine how any influence of the original fabric on peak and residual strength could ever demonstrate itself. In effect it would seem that the samples, even at an early stage of the experiments, have to be considered as 'remoulded' material and that most of the failure phenomena as well as the strength are *a priori* controlled by the particular set of experimental conditions. Well founded, contradictory evidence emphasizing the influence of natural and artificial soil fabric on soil strength has been presented by several others (e.g. Hvorslev, 1937, 1960; Bishop, 1966; Duncan and Seed, 1966).

It is again unfortunate that the Authors have spent so much effort on a material, certainly with a rather simple fabric pattern, on which a complex, partly unknown stress configuration obviously obscures the influence of the fabric pattern on the deformation and the strength. Clearly, real progress in the study of the influence of soil fabric on soil mechanical behaviour can only be expected if the total fabric patterns of a variety of natural soils are studied and described in detail. Appreciable direct and indirect support can be expected in many instances from the principles and techniques developed and the vast amounts of evidence collected in the fields of structural geology and rock fabric analysis. At some future stage this knowledge may allow artificial soil models, more closely resembling actual materials than that made by the Authors, to be prepared, tested, and observed under precisely known stress and strain conditions. Until such time, unfortunately, there seem to be few worthwhile, if any, methodological short cuts.

## REFERENCES

- ALTEMÜLLER, H. J. (1962). Gedanken zum Aufbau des Bodens und seiner begrifflichen Erfassung. *Z. Kult-Tech.* **3**, 323-336.
- AMBRONN, H. & FREY, A. (1926). *Das Polarisationsmikroskop*, 194 pp. Leipzig: Akad. Verl. GmbH.
- BALK, R. (1937). *Structural behaviour of igneous rocks*. Memoir 5, 177 pp. Geological Society of America.
- BISHOP, A. W. (1966). The strength of soils as engineering materials. *Géotechnique* **16**, No. 2, 91-128.
- BREWER, R. (1964). *Fabric and mineral analysis of soils*. 470 pp. New York: J. Wiley.
- CLOOS, H. (1928). Experimente zur inneren Tektonik. *Cbl. Min. Geol. Pal.* **28B**, 609-621.
- DUNCAN, J. M. & SEED, H. B. (1966). Anisotropy and stress re-orientation in clay. *Proc. Am. Soc. civ. Engrs* **92**, SM 5, 21-50.
- FOOKES, P. G. (1965). Orientation of fissures in stiff overconsolidated clay of the Siwalik system. *Géotechnique* **15**, No. 2, 195-206.
- FOOKES, P. G. & WILSON, D. D. (1966). The geometry of discontinuities and slope failures in Siwalik clay. *Géotechnique* **16**, No. 4, 305-320.
- FREUND, H. (Editor) (1957). *Handbuch der Mikroskopie in der Technik*, vol. 1, part 1, 681 pp. Umschau Verlag, Frankfurt-Main.
- GRIM, R. E. (1953). *Clay mineralogy*. 384 pp. New York: McGraw-Hill.
- HVORSLEV, M. J. (1937). Über die Festigkeitseigenschaften gestörter bindiger Böden. *Ingenvidensk. Skr.*, Ser. A, **45**, 1-159.
- HVORSLEV, M. J. (1960). Physical components of the shear strength of saturated clays. *Res. Conf. Shear Strength Coh. Soils*, Boulder: American Society of Civil Engineers. pp. 169-273.
- KUBIENA, W. L. (1968). *Entwicklungslehre des Bodens*. 215 pp. Vienna: Springer-Verlag.
- LAFEBER, D. (1962). Aspects of stress-induced differential movements of fabric elements in mineral soils. *Proc. 1st Conf. Austr. Rd Res. Bd, Canberra* **1**, 2, 1059-1067.
- LAFEBER, D. (1965). The graphical representation of planar pore patterns in soils. *Aust. J. Soil Res.* **3**, 143-164.
- LAFEBER, D. (1966). Soil structural concepts. *Engng Geol.* **1**, No. 4, 261-290.
- LAFEBER, D. (1967). The optical determination of spatial (three-dimensional) orientation of platy clay minerals in soil thin-sections. *Geoderma* (in press).
- LAFEBER, D. & WILLOUGHBY, D. R. (1967). Geometrical anisotropy and triaxial failure in soils. *Proc. 3rd Asian Reg. Conf. Soil Mech. Found. Engng*, Haifa (in press).
- MARTINEZ, J. D. (1958). Photometer method for studying quartz grain orientation. *Bull. Am. Ass. Petrol. Geol.* **42**, 588-608.
- MARTINEZ, J. D. (1965). The application of the photometer method in determining the crystallographic fabric of quartz in metamorphic quartzites. *Indian Min.* **6**, 97-118.
- MILNER, H. B. (1962). *Sedimentary petrography*. 4th edition, vol. I, 643 pp. London: G. Allen & Unwin.
- MORGENSTERN, N. R. & TCHALENKO, J. S. (1967). The optical determination of preferred orientation in clays and its application to the study of microstructure in consolidated kaolin. I. *Proc. R. Soc. A* **300**, 218-234.
- PETTIJOHN, F. J. (1957). *Sedimentary rocks*. 2nd edition, 718 pp. New York: Harper & Brothers.

- RIEDEL, W. (1929). Zur Mechanik geologischer Brucherscheinungen. *Cbl. Min. Geol. Pal.* **29B**, 354–368.
- SANDER, B. (1930). *Gefügekunde der Gesteine*. 352 pp. Vienna: Springer.
- SANDER, B. (1939). Gefügekunde und ihre Anwendungen. *Z. angew. Miner.* **1**, 285–312.
- SANDER, B. (1948). *Einführung in die Gefügekunde der geologischen Körper (Allgemeine Gefügekunde)*. 215 pp. Vienna: Springer-Verlag.
- SCHMIDT, W. J. (1957). Instrumente und Methoden zur mikroskopischen Untersuchung optisch anisotroper Materialien mit Ausschluss der Kristalle. See Freund (1957) 147–315.
- SKEMPTON, A. W. (1966). Some observations on tectonic shear zones. *Proc. 1st Int. Conf. Soc. Rock Mech.*, Lisbon, **1**, 329–335.
- TURNER, F. J. & WEISS, L. E. (1963). *Structural analysis of metamorphic tectonites*. 545 pp. New York: McGraw-Hill.
- WÄCHTLER, M. (1927). Über die Doppelbrechungserscheinungen in Kolloiden. *Fortschr. Miner. Kristallogr. Petrogr.* **12**, 119–192.
- WIENER, O. (1913). Die Theorie des Mischkörpers für das Feld der stationären Strömung. *Abh. K. sächs. Akad. Wiss. Math.-Phys. Kl.* **32**, 510–604.
- WILLOUGHBY, D. R. (1967). The geometrical description of linear and simple planar features in soils. *Aust. J. Soil Res.* **5**, 21–36.
- WU, T. H. (1958). Geotechnical properties of glacial lake clays. *Proc. Am. Soc. civ. Engrs*, SM 3, 1732, 1–29.

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The Authors have described experiments to study the effect of shear induced fabric on the resistance of a kaolin clay. Both this Paper and other papers by Morgenstern and Tchalenko (1967 a and b) are valuable contributions in the study of the role of orientation of particles and discontinuities in the mobilization of shear resistance of soils. They have conclusively shown that the birefringence ratio is independent of the thickness of the section and that the carbowax present does not affect this value.

According to Skempton (1964) the shear resistance of clays is reduced due to the preferred orientation of clay particles along the failure plane. The larger the degree of orientation, the nearer the value of residual angle of shear resistance  $\phi'_r$  to  $\phi_\mu$ , the angle of friction for the mineral, which may be considered to be the Hvorslev's angle of friction for the clay in the orientated state. The results obtained by the Authors in the present study are very significant. It is seen that the highly orientated structure of kaolin did not substantially affect the value of  $\phi'_r$  even when the direction of orientation was parallel to the direction of shear, whereas a precut plane reduced it to nearly half the value, which incidentally corresponds to the value of  $\phi_\mu$  for the mineral. This also agrees with the large reduction in  $\phi$  for soils with repeated shearing found by Borowicka (1965). The Authors therefore rightly concluded that although the particle orientation is strong on the average, sufficient local deviations exist to deter failure taking place at the residual strength and a virtually perfect alignment (or discontinuity) is necessary for the same.

In view of this it seems that in the case of a material like kaolin which exhibits a very high order of parallelism of the clay even at low stresses or states (West, 1964), the magnitude of the orientation does not signify that the value of  $\phi_e$  approaches  $\phi_\mu$ . The discontinuities seem to be the cause for this reduction. Studies on clays which do not exhibit such perfect orientation at low stresses are necessary to reveal whether the magnitude of preferred orientation is a measure of  $\phi_e$  and whether at perfect orientation  $\phi_e$  corresponds to  $\phi_\mu$ .

I have studied the role of soil structure on Hvorslev's angle of friction in the case of a montmorillonitic clay (Narain and Ayyar, 1967). In the experiments triaxial compression tests were conducted on different states of the clay. After failure the soil structure was measured from the slices cut out of the failure zone. Three methods, namely shrinkage