Applied Geology. — *Earth movements, caused by coalmining.* By J. VERSLUYS.

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Owing to the removal of coal by mining, a void is created and the equilibrium of the strata at a great depth becomes disturbed. As a result subsidences occur, that are observable even upon the surface.

While the coal is being removed, the roof is firstly propped up with timber, those props, however, are only able to withstand the pressure for a short time and they soon succumb. Nor is the erection of these props intended for the purpose of enduring permanent support. Often the space is left quite open, in many cases, however, this is filled up with lumps of stone. This filling in is seldom complete and the lumps are not firm enough to offer full resistance to the pressure of the strata resting thereon. They become crushed and occupy a smaller space. After a number of years the space occupied by the crushed filling material, is seldom more than 60 % of that occupied previously by the coal removed. Often the volume of the compressed mass is still smaller.

Formerly various opinions prevailed concerning the origin of the subsidences as a consequence of mining operations. An old view was that above the space, occupied previously by the coal, the rock had crumbled, so that the blocks fall and owing to this a natural filling would arise, in so far as the crumbled rock occupies more space than formerly. Consequently crumbling would only go on to a limited height, proportional to the thickness of the coal bed. In that case nothing would be observed on the surface, provided the depth of the coal bed was great enough.

As against this view was another, much older one, namely that the series of beds lying over the area from which coal had been removed, subsided altogether, hence fractures arose at the extremes of the field, perpendicular to the strata. In the case of fig. 1, where *AB* represents the space from which coal has been removed, the mass *ABDE,* would slip along the lines *BD* and *AE,* and subside. Regarding these older theories reference is made to the works of J. GONOT (1), G. DUMONT (2) and a report by the "Union Des Charbonnages" of Liége (3).

These theories have become obsolete as have also the variations of those theories, and the assumptions, in which endeavours are made to reconcile both theories.

Afterwards the theory that now almost generally prevails, that of the deflection of beams arose. It is taken that the strata above the space from which coal has been removed, may be considered as beams that are fixed in at the extremeties and become deflected. For this theory of deflection, reference is made to text books, i.a. to that by A. H. GOLDREICH (10). Further, attention must still be drawn to the researches and theories of L. THIRIART, from whose hand new publications are continually appearing (lately 15).

The prevailing theories will not be further discussed here. In 1928, in all probability, a more extensive special article, with a more complete bibliography, will apear in the Dutch periodical "De Ingenieur".

Here only will be treated a new explanation of the phenomena observed and with this it will be presumed that the most simple case occurs, viz : that the coal bed lies horizontally.

One of the first questions arising is : If the strata covering the carboniferous consist of loose beds, as sand and clay, will those materials then flow? This question can be answered in the negative. In Dutch-Limburg and Belgian-Limburg (Kempen), where considerable covering strata for the greater part, sand, prevail, the phenomena on the surface of earth do not deviate from those which occur near Liége and in the Borinage, where the firm rock is only covered by a few metres of loose material. Where sand is also lying on the surface, clear evidences of gravity and thrust faulting are to be observed, and these, in this case, have much resemblance to the natural faults in sand. On digging a trench tor making a road at Heerlen in 1926 an opportunity occurred of seeing a fault in loose beds (13) owing to which comparison was possible.

It must therefore be taken that the subsidence owing to mining, takes place so gradually that the sand does not become running sand (9).

If fig. 1 represents a vertical section of a developed coalfield, and in this

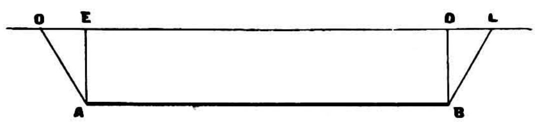

Fig. 1.

the line *AB* represents the part of the coal stratum that has been removed, and *OL* the earth surface, subsidence occurs with a steep incline, about as the lines *AO* and *BL*. A shortening of the surface *ED* is observable, and in the sections *OE* and *DL*, an extension. The influence of the shortening is visible on the buildings, pavement curbs, tramlines, railings, paving stones and such like, owing to compression. Some very remarkable changes of form, which will not be discussed here, are seen. The extensions are similarly observable. What takes place to the left of *O*, and to the right of *L*, in fig. 1, will still further be, at first the conduct of the strata within the trapezium *OABL* will be described.

Previous to a commencement being made with mining operations, the strata overlying the coal rest upon the latter, and there is an equilibrium. This equilibrium is not definite, under varying conditions of stress the mass can be kept in balance, owing to friction and since a certain force is necessary, to overcome the resistance to tension of the consolidated strata. It is not necessary, though probable, that the vertical stress deviates little from the pressure which a fluid with a specific gravity, equal to that of the beds, would exercise, provided the latter may be considered as being impermeable for water. The horizontal stress may have varying values.

While the coal exerts a certain pressure upwards on the roof, this ceases altogether for a moment, owing to the removal of the coal along the line *AB* in fig. 1. Very soon, however, a pressure that is smaller takes the place of this. This counter pressure is effected by the filling in material, or owing to crushing taking place up to a slight height above the space from which coal has been removed. According to observation this results in the equilibrium being disturbed, real gravity faults occur, at the edges of the field, and horizontal compression and extension, as discussed in the forgoing. As will appear presently the lengthening is to be attributed to gravity faulting, and shortening to thrust faulting. Energy is used up by the crumbling of the filling material, by the formation of fractures in the solid rock and further, by the frictions of the solid parts ; these three kinds of energy are produced by gravity : the mass situated within the trapezium *OABL* in fig. 1, subsides. Within this trapezium sometimes apparent risings are seen on the surface, presumably, however, these are sections that have declined less than the other, owing to thrust faults with smaller heights. A full discussion of the mechanics of deformations in the masses of earth under the influence of the changes in condition of stress can be neglected here. We refer for this to the works of H. KREY (11 and 14). The results of the various tests, i.a. those referred to in the first mentioned work by H. KREY (11) can be applied immediately to what occurs in the trapezium.

In figs. 2 and 3 the rectangles *ABCD* represent the vertical sections of

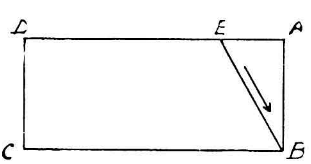

Fig. 2.

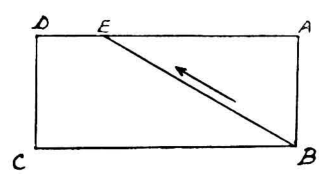

Fig. 3.

receptacles filled with sand, hence *AD* in both the drawings represents the surface of the sand masses, while the end *AB* can be removed parallel to itself. The sand exercises a pressure on the side *AB*. If the pressure from outside, upon this side, be reduced, the mass *ABE* then moves in the direction *BE* in fig. 2, forming an angle with the horizon of about 60°. If however the pressure on *AB* be so much increased that the sand gives way, the mass *ABE* then moves in the direction *BE* in fig. 3, forming an angle with the horizontal of about 30°.

If thus the pressure be reduced in a definite direction, so that movement sets in, then the plane of faulting forms an angle with that direction of about 60°. It may be presumed that owing to the diminishing of the pressure along *AB* in fig. 1 within the rectangle *ABDE*, the vertical stress has become smaller and consequently deformations set in, owing to movement along the planes, forming an angle of 60° with the vertical, or one of 30° with the horizon. This mass thus becomes horizontally compressed and the phenomena occurring within this section, are thrusting faults, and the rectangle *ABDE*, becomes shorter horizontally.

The horizontal pressure on the lines *BD* and *AE* in fig. 1, is reduced, and displacements will take place over a plane having an inclination of about 60°. It would be conceivable that the gravity displacement occurs in two planes *OA* and *BL* in fig. 1, and the thrust in one or two planes. On displacement one plane prevails, there are, however, others and these effect an extension of the surface as appears from fig. 4. In the same manner other displacements effect a contraction.

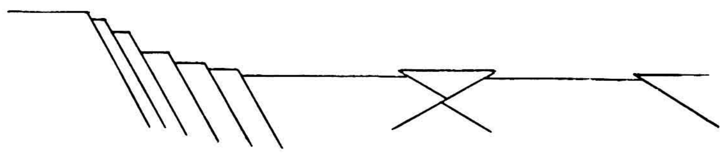

Fig. 4.

PUSCHMANN (5) discusses observations, in a number of tunnels, which had been cut in the coal beds overlying, one or more deeper beds which had already been worked.

From that description it appears that the sandstone strata, overlying the void from which coal had been taken, underwent but slight deformation. The slate appeared to be slightly folded. So the explanation given above holds strictly only for the unconsolidated upper beds, while the carboniferous sandstone and slate show some deviation. The sandstone hardly becomes contracted, above the space from which coal has been removed, and in accordance with this the fracture (*BL* and *OA* in fig. 1) in sandstone beds is practically vertical. Every sediment has its own character and the angle of inclination of the fractures depends upon the nature of the material (12).

Outside of the lines *OA* and *BL* in fig. 1 the ground also moves on account of the mining in the part *AB* of the coalbed. This can be explained according to the same principle as the foregoing. The pressure upon the strata below the line *AB* in fig. 1, declines and thus fractures might arise at a slight angle of inclination. The case, however, is not so simple, and might be better compared with a test that is also described by H. KREY, from which fig. 5 has been taken. A vertical pressure is effected upon a stamp *AB* resting on a mass of sands till the stamp presses the sand away.

The mass then moves as is shown in fig. 5. If the pressure on *AB* is previously already great enough to effect this change of form, this can be prevented by a pressure upon the mass of sand from *A—B* and *B—D*. If after this the pressure outside the stamp be reduced, the change of form will also set in. In this manner it may be taken that in fig. 1, by reducing the pressure the upward movement along *AB* takes place under a slight inclination, and that the mass to the left of *OA* and right of *BL* declines. In this then faults also occur, and on the surface, to the left of *OA* and the right of *L* some horizontal extension and subsidence may be expected. This is represented in diagram in fig. 6. There is less certainty concerning the inclination of the faulting planes in this region. The movement in the bottom of the coal layer being worked on, is only too well known in the mines and the movement outside of the main fractures in the ground has been observed in shafts, owing to accurate measurements, without this causing any material damage. In fig. 6 left of *O* and to the right of *L* extension must take place on the surface. The sphere of displacement and extension left of *O* in fig. 6, connects up with *AOE* in fig. 1 and left of what is represented in fig. 4. Owing to the succession of strata having different physical characteristics, the situation here will also become changed.

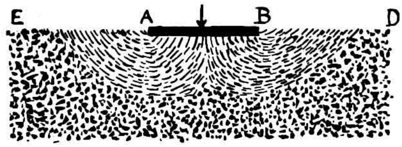

Fig. 5.

With regard to the effect outside of the main planes of fracture, it would appear that in 1899 W. H. TROMPETER (4) held the same view. He speaks of an "expansive force" of the rocks, as the cause of the movement, apparently, however, this writer expressed himself inaccurately and something else is meant by "expansive force". For the rest it is not impossible that clay and soft shale expand, on a reduction of pressure (16). This does not occur in the Limburg coal mines, presumably the rock in this district, at one time, owing to the load of deposits which later disappeared again for a great part owing to erosion, were, under so great a pressure, unable any longer to expand by the absorption of water.

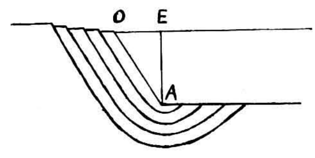

Fig. 6.

A question of importance with mining is how the shafts can be protected. To protect these completely, as a rule much of the coal around the shafts, has to be sacrified. In this connection it must be pointed out that in one of the mines in Belgium, only a small pillar was left around the shaft, apparently with success, though the formations overlying the carboniferous,

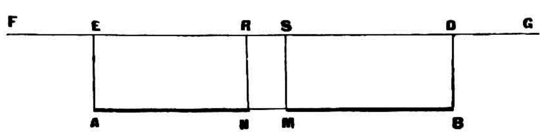

Fig. 7.

for the greater part, consist of sand, having a considerable depth. We then have the situation as in fig. 7. Over the section *MN* the vertical pressure at the top and the bottom of the coalbed, is not directly altered. The displacements will thus avoid this section of the area. The subsidence taking place outside the limits of the field being worked, (outside *AO* and *BL* in fig. 1), as a result will have a decline to a much greater degree at *MNRS* and thus the section *MNRS* will decline, the vertical pressure, however, in *MNRS* will then also decline much less than in the adjoining sections. Hence the section *MNRS* can be compared with the stamp in fig. 5. It must be borne in mind that if in fig. 7 the coal in section *AN* only, be first removed, and only later that of the section *MB*, the main fractures will go through the section *MNRS*, because then the line *MS* may be temporarily compared with the line *AE* in fig. 1. The situation becomes quite otherwise if, as in fig. 7, is presumed, the coal is removed simultaneously from the sections *AN* and *BM*.

If the principles here explained be correct, the great protecting pillars can be worked, provided work be effected as symetrically as possible with respect to the shafts and that near these a narrow strip of coal, perpendicular to the direction in which the coal beds are being worked be left untouched.

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