# MINING SUBSIDENCE IN TWENTE, EAST NETHERLANDS[1]

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## ABSTRACT

Wassmann, T. H. 1980 Mining subsidence in Twente, East Netherlands – Geol. Mijnbouw 59: 225-231.

A method for forecasting the vertical and horizontal movements of points at the surface caused by salt-mining subsidence has been developed for the special case of the Hengelo field. All possible data of a first case of caving-in of cavities created by the solution mining of salt were collected and studied. A theory was set up to explain two striking differences from other subsiding areas, i.e. the duration in time of the subsidence and the small area influenced at the surface in relation to the depth of the cavity mined out. Special attention is paid to the behaviour of the Triassic claystone formation ('Red Beds') above the salt layer. In 1973 this theory was used to predict the rate of subsidence of a second case over a 10 year period. This second area of subsidence was situated just under a new brine purification and vacuum plant. For each part of the installation within this area the movement with time was calculated. With these figures it was possible to arrange a long-term planning for preventive maintenance and by doing so to keep the complete plant operating.


## INTRODUCTION

In 1918, Koninklijke Nederlandse Zoutindustrie (KNZ) started solution mining of salt in the Boekelo area, Twente, East Netherlands (Fig. 1). In 1933, KNZ moved to the nearby Hengelo area because of better transport facilities available on the Twente-Rijn canal.

The total production of salt in Boekelo amounted to about 1,445,000 metric tons from eight single production wells. The production in Boekelo ceased in 1952. In the 1977 leveling no subsidence whatsoever was measured.

In Boekelo and Hengelo the geological profile down to the base of the salt is about the same and is given in figure 2. The Quaternary and Tertiary formations consist of an unconsolidated, very plastic clay with only some sand in the upper thirty metres. The Triassic begins directly under this clay at a depth of about 120 m with the Muschelkalk marl. Only in the northern part of the Hengelo concession is the Muschelkalk missing. Below the Muschelkalk we find the Upper Bunter claystone or 'Red Beds' with the Rötsalt Formation at their base with an average thickness of 50 m. The Red Bed claystones are dry, tight and impermeable. This formation is very consistent throughout the whole concession with a thickness of 180 m. Figure 3 gives an idea of the depth, strike and dip of the top of the salt. The strike is northwest-southeast with a dip of about six degrees towards the southwest.

In 1963 the first subsidence was measured at area 1 (Fig. 3), just within the Muschelkalk border. Ten years later a second case of subsidence occurred in area 2, just a few hundred metres to the north and just outside the area of the Muschelkalk deposit. Unfortunately this second subsidence was situated under the new brine purification and vacuum plant.

The ten year lapse between these two cases provided an opportunity to study the behaviour of area 1 thoroughly. Armed with this knowledge, it was possible to predict the second subsidence and to prevent severe damage to the salt production plant.

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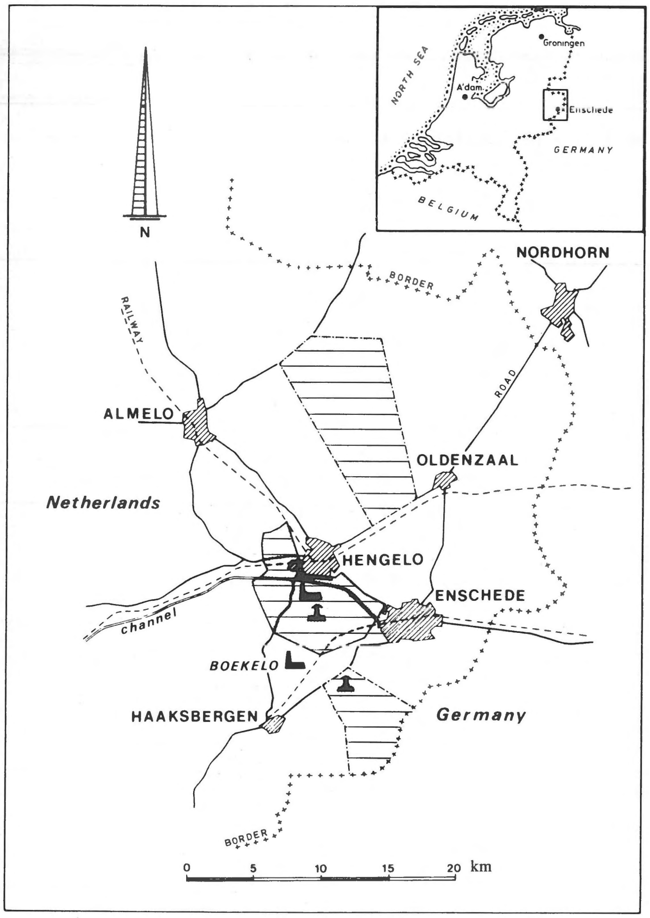


Fig. 1
Akzo salt concessions in east Netherlands (marked by horizontal lines).

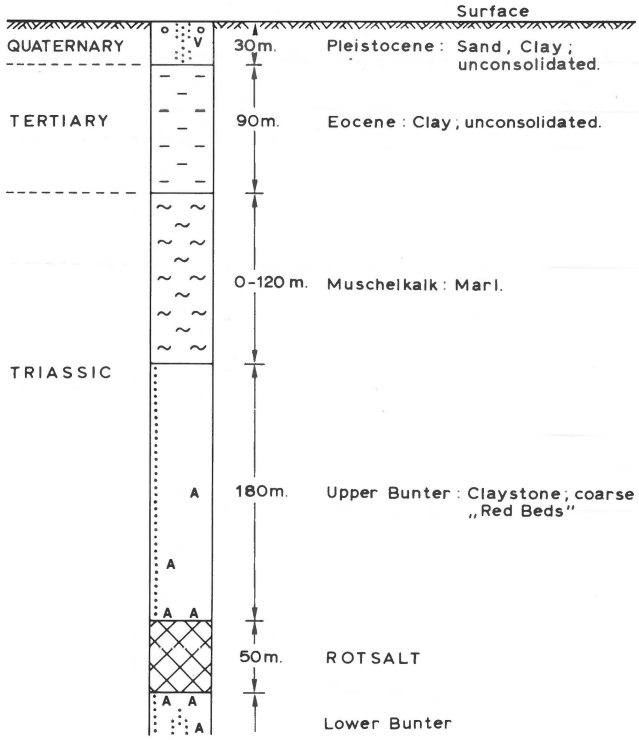


Fig. 2
Geological profile of the Akzo concession 'Twenthe-Rijn' (east Netherlands)

## SUBSIDENCE CASE 1

Well number 18 was drilled in area 1 in 1949 and followed in 1951 by well number 24 at a distance of only 25 m (Fig. 4). Both wells were taken out of production in 1958, five years before any subsidence was measured. It is difficult to trace accurately the production of salt from each individual well because of the numerous connections existing between the cavities of neighbouring wells. In total the wells 16 to 22, plus well 24 (all more or less situated in area 1) have produced 1,385,000 tons of salt. This is about the same tonnage of salt from an equal number of wells in Boekelo, but in Hengelo the production rate is higher and the cavities are interconnected as can be seen in figure 4. In this figure the cavity diameter is also reproduced on the basis of calculations using production figures, while assuming the shape of an inverted cone.

Then in our second halfyearly periodical measurements in 1963, a subsidence of 30 cm was found in comparison with the first measurement in 1963. In figure 5 the results are given for the first four years. The bench marks 44 to 56 pass through the centre of the subsidence bowl at centres of about 20 m. The vertical movements are given in millimetres. In 1966 the

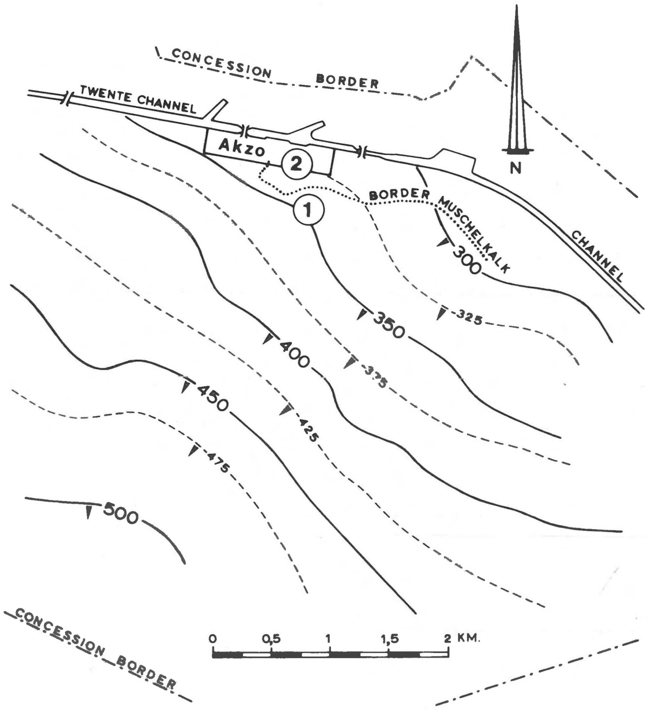


Fig. 3
Structure map on top of the Hengelo salt with the areas of subsidence 1 and 2.

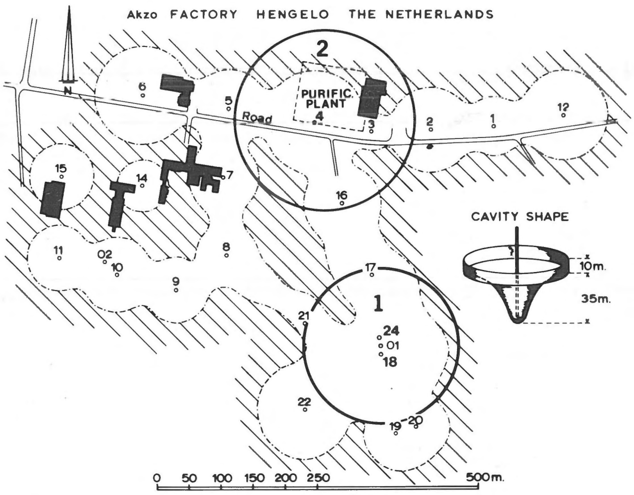


Fig. 4
Reconstructed cavities based on salt-production figures, Akzo Hengelo, The Netherlands.

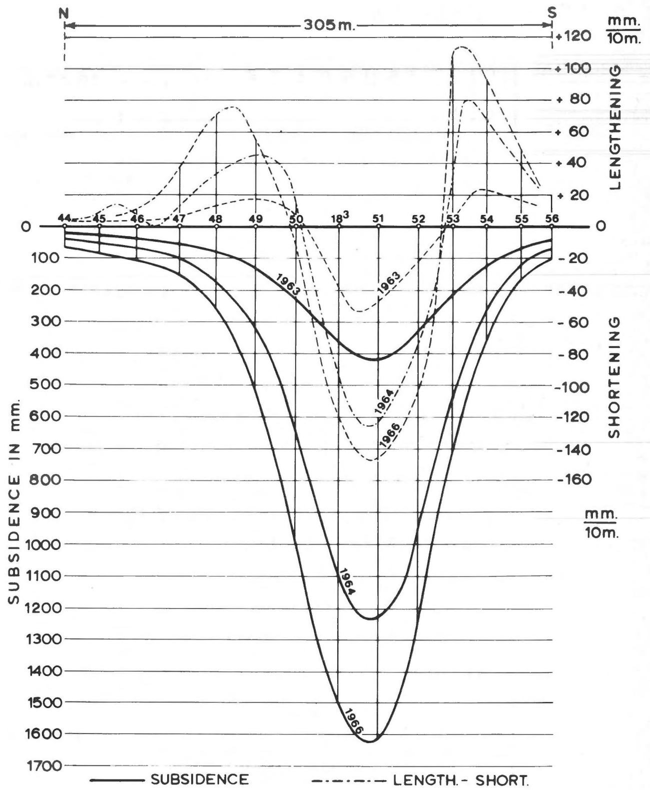


Fig. 5
Results of measurements of the horizontal and vertical displacements of bench marks in area 1 during the period 1963-1966.

subsidence measured in the centre was 1625 mm. The horizontal displacement of the bench marks or the strain is given in millimetres per ten metres of length. The measurements showed similarities to subsidence figures for the Dutch coalfields under static conditions of the winning front, as can be seen in this figure by the stable zero strain point.

There were, however, two great differences: the duration in time of the subsidence and the small area influenced at the surface in relation to the depth of the cavity. As the coalfield practice showed, movements at the surface ended after about two years. In the Hengelo case, however, the subsidence has lasted for years. At this very moment, after 15 years, a vertical displacement of about 50 mm is still measured in the centre of the bowl every year.

Unfamiliarity with what actually was happening underground made KNZ decide to drill an exploration well between wells 18 and 24 in this area. After the Triassic formation had been reached great difficulties were encountered owing to a complete loss of circulation. In consequence no cutting reached the surface. Several cores were taken to trace the guide horizons. In total 68.40 m were cored with a recovery of 65.3%, while normally a recovery of 95 - 100% is obtained in these formations. The drilling reached the undisturbed and still undissolved base of the salt as can be seen in figure 6. Between wells 18 and 24 some 8 m of rock salt were found. Figure 6 shows the reconstructed original geological profile between wells 18 and 24 before any subsidence, in comparison with the profile actually found in this exploration well 01. The most noteworthy guide horizons have been marked in this figure. In this well a vertical displacement of about 26 m was found at a depth of 340 metres, whereas the subsidence at the surface amounted to only 1.85 m at the same time.

The following conclusions could be made after completion of the exploration well 01:

(1) The Quaternary and Tertiary clay formations are plastic enough to avoid rupture or faulting.
(2) The Triassic Muschelkalk and Upper Bunter formations are completely broken. Open fissures and small cavities of several metres could be traced during drilling and logging.
(3) A cavity in the salt layer was not found because of the collapsed roof.

Because the cavity collapsed several years after the shut-down of the wells, the structural failure of the roof rocks is due to more than the big span of this roof. There must be another reason. The Bunter Red Beds can easily be moistened by water or brine so that the claystone loses its structural strength. As has been noticed in other abandoned but not plugged wells, the roof of the cavities will collapse in beds of about 10 to 30 m thickness over the years.

In 1963 the caving could finally reach the unconsolidated Tertiary clay. From that moment on a pronounced subsidence was measured on the surface. After a certain amount of time the subsidence is no longer directly related to the caving of the roof formations. The compaction of the rubble in the disturbed layers will be responsible for a very slow decreasing but long-lasting subsidence at the surface. Nevertheless the small area influenced at the surface with a diameter of only 270 m could not be explained in relation to the depth of the original cavity at 340 m (angle of draw).

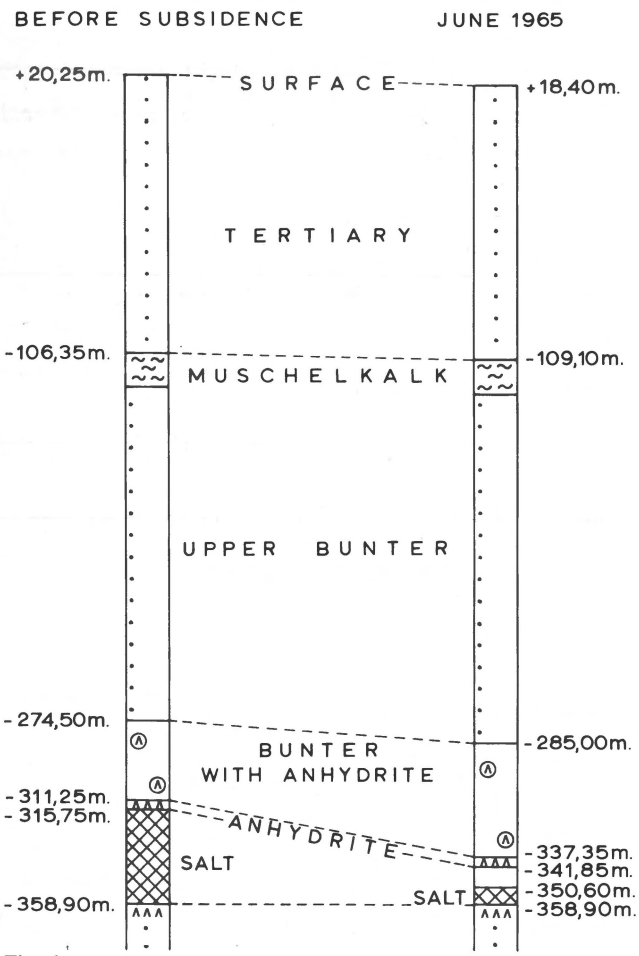


Fig. 6
Geological profile of the Akzo Well 01 after 2½ years of subsidence.

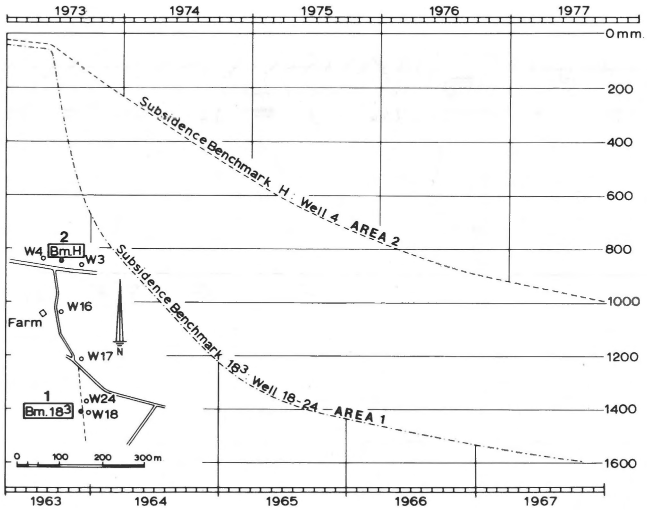


Fig. 7
Comparisons of the rate of subsidence of bench marks in the two subsiding areas, Akzo Hengelo, The Netherlands.

## SUBSIDENCE CASE 2

In 1973 subsidence was measured in a second case during the periodic leveling. The centre of this new area was situated near the old well 4. After a year of thorough measuring this new situation could be judged and the similarities and differences be seen between this case and case 1. The geological profile of well 4 is about the same as that of wells 18 and 24. Only the 15 m of Muschelkalk are absent here.

Well 4 was taken out of production in 1959. By that time this cavity was connected to several other cavities and was situated in the middle of a T-crossing (Fig. 4). From the salt-production figures and the history of repair jobs on this well, it was known that the dissolving height in the salt layer had been lost very fast. Because of this fact the shape of the cavity will look like a small inverted cone. The connections to the neighbouring wells were made just under the roof of the rock salt. This means that the cavity of well 4 had less space for storage of broken rock material. It was no surprise, therefore, that a much slower rate of subsidence was measured at the surface in this area.

Figure 7 shows the difference in the subsidence rate of two bench marks at the same distance from the centre of the subsidence bowl in both areas. As can be seen in this figure, the subsidence rate of area 1 is much higher in comparison to that of area 2 for the first three years. After three years the rate in area 1 has decreased to a more or less constant figure of about 80 mm a year. In area 2 the rate of subsidence has stabilized for the time being at a figure of about 60 mm a year after the same period of three years. In area 2 the same comparably small area of influence was also found.

From laboratory experiments on cores, a maximum advisable diameter of about 80 m was calculated for the brine-filled cavities in the Hengelo field. However, in these calculations changes in the mechanical properties owing to wetting of the rock formations, and especially the Red Beds, were not considered. Now it is known that water or brine will penetrate

Table I
Prognosis of the Subsidence of Bench Mark H (Area 2) over the Period 1973-1983 in Comparison with the Subsidence Actually Measured of Bench Mark 18[3] (Area 1) in the Period 1963-1973

| Bench Mark 18[3] | | Bench Mark H | | |
|---|---|---|---|---|
| Year | Actually measured (mm) | Year | Prediction (mm) | Actually measured (mm) |
| 1962 | 21 | 1972 | 21 | 21 |
| 1963 | 653 | 1973 | 311 | 311 |
| 1964 | 533 | 1974 | 300 | 299 |
| 1965 | 207 | 1975 | 200 | 196 |
| 1966 | 99 | 1976 | 125 | 113 |
| 1967 | 82 | 1977 | 75 | 94 |
| 1968 | 82 | 1978 | 64 | |
| 1969 | 81 | 1979 | 60 | |
| 1970 | 81 | 1980 | 60 | |
| 1971 | 80 | 1981 | 60 | |
| 1972 | 80 | 1982 | 60 | |
| 1963-1972 | 1987 | 1973-1982 | 1315 | |

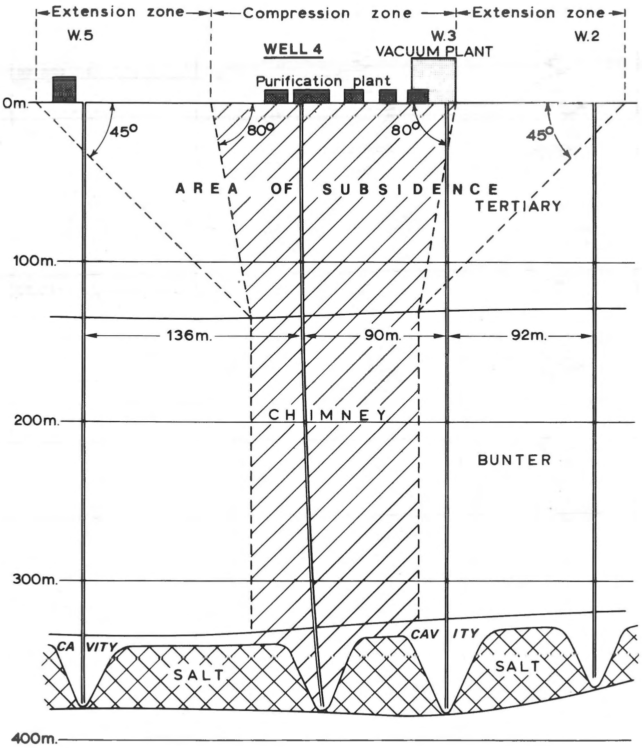


Fig. 8
Idealized section over subsidence area 2 of Well 4.

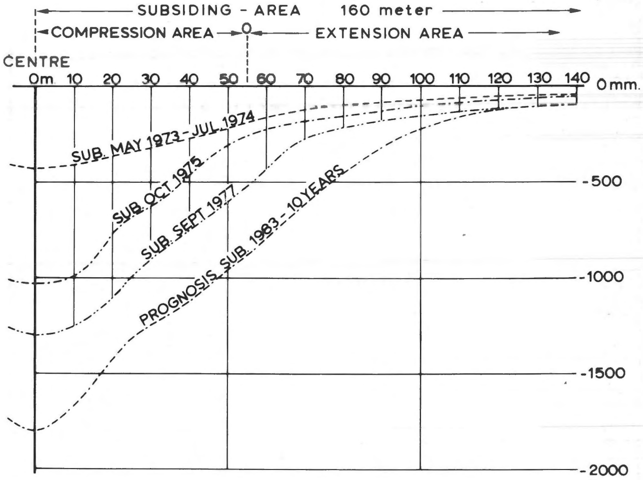


Fig. 9
Actual measured and predicted subsidence in area 2 during the period 1973-1983.

into the normally tight and impermeable claystones owing to capillary forces. But it is only thought to be possible in an upward direction where the internal stresses are more or less released owing to undercutting by the open cavity. The walls of the cavity are still under the influence of the overburden pressure and not accessible to penetrating fluids. This process will creep slowly but steadily upwards depending on the height of the capillary action, and bed after bed of the roof formations will collapse in the cavity. There is some proof from logging in old, but still accessible, wells that this process actually takes place.

## FUTURE UNDERGROUND DEVELOPMENT

Eventually this leads to the following picture of the underground developments (Fig. 8). The moistening of the roof rock above the existing cavity will create a chimney filled with broken rock material. Depending on the storage capacity of the cavity, this chimney will either reach the unconsolidated formations or not. If the unconsolidated clay is reached, a normal subsidence bowl will develop with a slope equal to the angle of draw of 45° for this kind of rock. This explains the relatively small area of influence in relation to the depth of the original cavity. The plane of break or fracture has been found at a much steeper angle. This plane intersects the surface at a line connecting the points of the largest extension. This angle is about 80° in the Hengelo field. If one reckons with a 15%

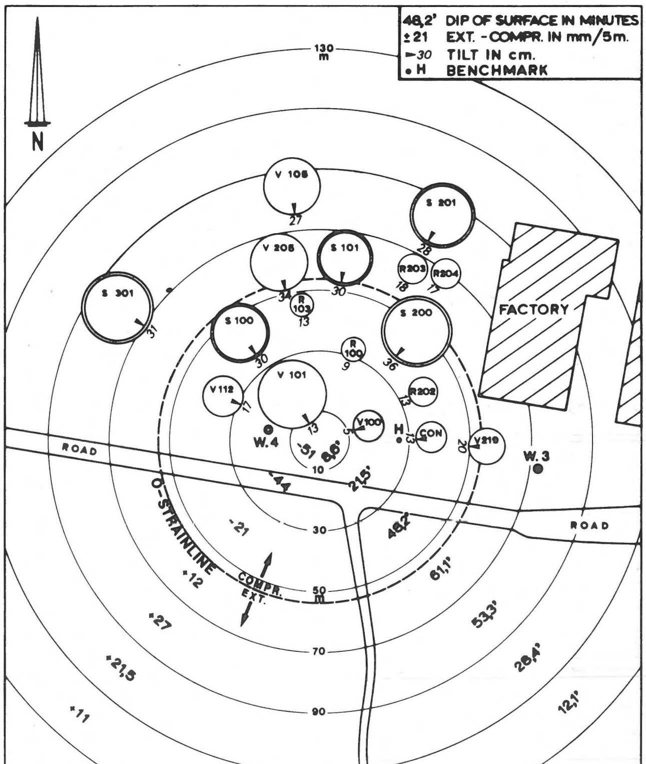


Fig. 10
Predicted figures for tilt and strain at the surface for the 10-year period.

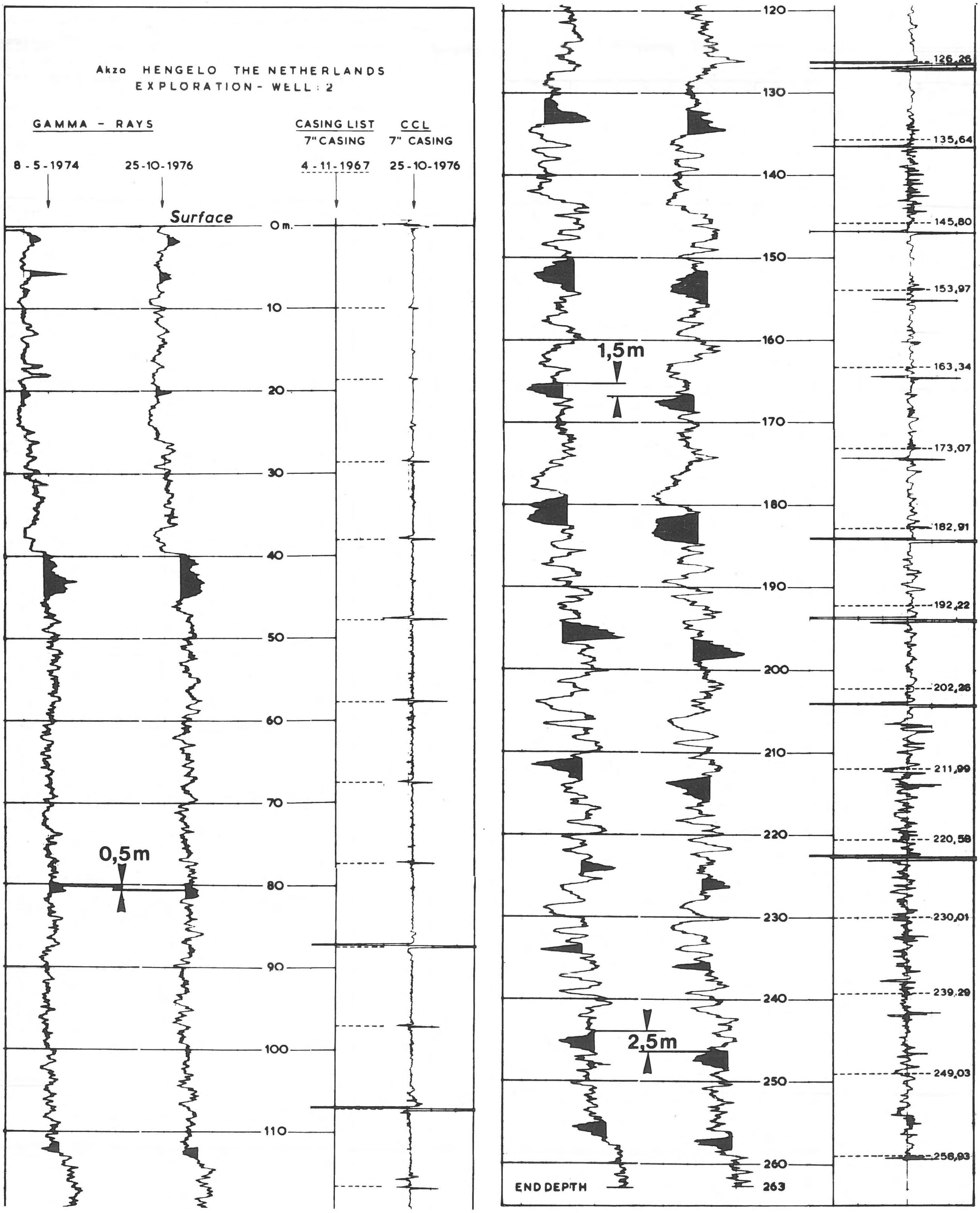


Fig. 11
Vertical displacements increasing with depth due to caving of a cavity in a salt layer, measured by GR and CCL in the Hengelo field.

Table II
Tilt of the Purification Tanks in Minutes and Centimetres till 1983

| Tank | Diamter (m) | Distance to centre (m) | Tilt (minutes) | Tilt (cm) |
|---|---|---|---|---|
| V 100 | 11.00 | 10 - 20 | 15.5 | 4.9 |
| V 101 | 22.40 | 5 - 30 | 19.3 | 12.5 |
| V 105 | 19.07 | 75 - 95 | 48.1 | 26.7 |
| V 112 | 14.25 | 30 - 40 | 41.3 | 17.1 |
| V 205 | 19.07 | 50 - 70 | 61.0 | 33.8 |
| V 219 | 10.90 | 50 - 60 | 61.9 | 19.6 |
| Cond. | 10.90 | 30 - 40 | 41.3 | 13.1 |
| R 100 | 8.00 | 30 - 35 | 37.8 | 8.8 |
| R 103 | 8.00 | 40 - 50 | 55.0 | 12.8 |
| R 202 | 10.00 | 35 - 40 | 44.7 | 13.0 |
| R 203 | 10.00 | 60 - 70 | 60.2 | 17.5 |
| R 204 | 10.00 | 65 - 75 | 58.4 | 17.0 |
| S 100 | 18.30 | 35 - 55 | 54.1 | 28.8 |
| S 101 | 17.00 | 50 - 70 | 61.0 | 30.2 |
| S 200 | 22.00 | 35 - 60 | 55.7 | 35.6 |
| S 201 | 20.00 | 75 - 95 | 48.1 | 28.0 |
| S 301 | 20.00 | 70 - 90 | 53.3 | 31.0 |

swelling of the claystone by moistening, with a cavity shape of an inverted cone and the calculated volume of 360,000 m$^3$ for well 4, this cavity can just store the whole Triassic cylindrical column. So in this case, the slow rate of subsidence measured is caused by the compaction of the rubble pile above the cavity. The base of the unconsolidated Tertiary clay is found at a depth of 135 m. Using an angle of draw of 45° (a similar angle as has been found in the Dutch coalfields), the radius for the area influenced can be calculated to be about 135 m. This figure is in extremely good correspondence with the figure actually found in both cases.

## PREDICTION OF SUBSIDENCE

Considering this theory and the differences between the two cases, an attempt was made to forecast the vertical and horizontal movements at the surface in area 2 for the subsequent ten-year period. This task was of utmost importance in keeping the salt factory running. The purification plant, quite an intricate plant, is built on an overflow principle and flow directions would be reversed due to the subsidence. Numerous pipelines would be subjected to horizontal forces so that measures had to be taken to avoid rupture of these pipelines.

Table I shows some of the predictions made in 1974. In the second column the measured subsidence of bench mark 18$^3$ in area 1 is shown, while in the fourth column it is compared with the predicted subsidence of bench mark H in area 2, both for the first ten year period. Finally, the last column gives the actual measured subsidence of bench mark H until 1978. Of course, there were predictions for many points in the subsiding area. Figure 9 gives the predicted subsidence for a line from the centre of the bowl towards the east, compared with the subsidence profiles actually measured over the same line.

The subsidence in this area started in May 1973, so the September 1977 line is already nearly half the prediction. However, by this time the volume of the subsidence bowl is only 17% of the volume of the original cavity.

Figure 10 is a very simplified lay-out of the purification and the vacuum plant. In this plan the predicted figures are given for the angle of tilt in minutes and for the shortening and lengthening in millimetres per five metres of length at the surface. The figures are given for circular areas around the centre of subsidence. It is an idealized situation, because in reality the subsidence bowl has more or less the shape of an ellipse with its longest axis in the northeast-southwest direction. This direction coincides with the direction of dip of the salt layer.

## PREVENTATIVE MAINTENANCE

What can be done with these results? The purification tanks have numbers that correspond with the numbers in the first column of Table II. The next two columns of Table II give their diameters and the distances from their nearest and farthest point to the centre of the bowl.

From the map, the average tilt in minutes of the tank can easily be read and this figure can be recalculated to a tilt in centimetres on the basis of the diameter of the tank. All the expected movements of construction features on the surface within this area can be found from this kind of table. With these figures it was easy to arrange a long-term planning for preventive maintenance. For example, the purification tanks were jacked up and put on a mound of stabilized sand to restore the flow direction between the tanks. The height of these mounds was calculated from the tables, as was the expected tilt. All tanks were then given a tilt in the opposite direction. It is expected that the tanks will move downwards again and tilt back to a horizontal position, or even further without maintenance needing to be done within the next five years. The same has been done with a small building with a stiff reinforced concrete foundation and brick walls.

Finally, figure 11 shows a Casing-Collar-Log and a Gamma-Log of a suspect well. On the surface no subsidence has been measured up till now. Yet the expectation is that something will happen in the near future. This well is still accessible for logging and it is planned to make these logs every year. In this figure the original casing list is compared with a Casing-Collar-Log taken in 1976 and a 1974 Gamma-Log is compared with the Gamma-Log of 1976.

In both logs a vertical displacement increasing with depth can be noticed distinctly. At a depth of 250 m a vertical displacement of about 2 m can be read from the logs, whereas at a depth of 80 m the displacement is only half a metre.

These movements have already reached the unconsolidated clay and will probably soon be measurable at the surface. This kind of information is considered to be a first warning of possible future surface movements.