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Mining Subsidence Engineering

Translated by R. F. S. Fleming

With 380 Figures

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Preface

This book originally appeared in German in 1974, under the title "Bergschadenkunde" (mining subsidence engineering), and then in Russian in 1978, published by Nedra of Moscow. When the German edition was almost out of print, Springer-Verlag decided to bring out a new edition, this time in English. For this English version the text has been thoroughly revised, enlarged, and supplemented by over 100 new figures.

The book deals with the current state of international knowledge on strata and ground movement over mine workings, with its damaging effects on mine shafts and the land surface, and with measures for regulating mining damage in law and reducing it in practice. Discussion begins with the mine excavation underground – the cause – and ends with the damage to surface structures – the effect. Methods of roof control, including the subject of rock bursts, are not discussed, since that is a field concerned more with the safety of underground workings than with minimizing damage at the surface. Of the 500 literature references in the German edition, only the more important for an international readership have been retained, but no value judgement on the many publications not mentioned should be read into this.

The book is principally intended as a working aid for the mine surveyor, the mining engineer, the architect, and the civil engineer. For the student and the post-graduate researcher, it offers a summary and guide to this whole field of knowledge. In addition, it should provide a rapid survey of this special field for those who are temporarily concerned with mining damage – in law, for example, or in town planning, or as landowners.

To translate the German text for this English edition, the publishers were able to secure the services of Mr. Richard F. S. Fleming in London, who, as a well-known translator for publishers of technical journals and books in the mining field, was particularly well qualified to provide an accurate English rendering both of the specialized mining terms and of the difficult technical discussion. Thus, in two years of conscientious translating, an English technical manual has been produced which faithfully reflects the now revised and enlarged German original. For this, and for his close collaboration, I am greatly indebted to Mr. Fleming. The new figures have again been drawn by Mr. Horst

Conrad, who also designed the cover. Many colleagues and many technical experts abroad, above all in Poland and Britain, have given me their advice and assistance on special aspects. I thank them all, and not least the publishers, who have all along advanced the project with great energy, for their valuable assistance.

Berlin (West), March 1983 Helmut Kratzsch

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Introduction

Wherever minerals are won by underground mining extending over any significant area, the overlying rock mass subsides into the underground cavities opened up by mining, and the upper surface of the ground subsides correspondingly, forming hollows and trenches, open cracks in the earth, abrupt steps, and extensive subsidence troughs. Ground can sink vertically or be displaced horizontally – or both – by as much as several metres. Since the middle of last century, and particularly over the coalfields of Europe, ground movements on this scale have led to severe damage to buildings, communications, and agriculture, for which the aggrieved land and property owners have demanded compensation from the mine operators and, when necessary, have pressed their claims in the courts. To be in a position to present an effective defence against unjustified claims, mine surveyors have since the beginning of this century made numerous measurements of underground excavations and observed ground movements with extreme care. From the experience thereby gathered, and the theoretical conclusions drawn on how ground movements develop, there has gradually been evolved a new branch of science and technology – *mining subsidence engineering* – which has been taught in German mining academies since 1931.

At first all that was required was a knowledge of the extent of surface damage and the duration of surface influence of a mine working, together with the ability to attribute an appropriate share of costs to neighbouring mines, which very often were jointly responsible for the damage; but with increasing mining activity underground and increasing residential development on the surface, it became necessary, both to the mine operator and to the surface developer, to do everything possible to minimize mining damage. Today therefore, it is the *task of subsidence engineering* to develop procedures for –

a) predicting strata and ground movements over mine workings;
b) ascertaining the effects of such movements on building structures, mine shafts, etc.;
c) minimizing subsidence damage by means of improvements in mining, protection of structures, regional planning etc.

From this description of its role, it follows that mining subsidence engineering, although certainly to be counted among the earth-engineering sciences, takes in not only the study of ground movements and rock structure but also areas bordering on the sphere of mine surveying, like mining law, property law, mining engineering, constructional engineering, rock and soil mechanics, communications engineering, agriculture, hydrology, town planning, etc. (see Table 1).

Table 1. Division of the earth-engineering sciences as between construction and mining

Geomechanics (earth engineering)			
Construction (foundations, embankments, tunnels)		Mining (underground and opencast)	
Soil mechanics (loose ground)	Rock mechanics (firm rock)	Strata control (in vicinity of workings)	Subsidence engineering (remote from workings)

With the increasing depth of mining, its impact began to be felt even by the numerous mine structures, and especially by *mine shafts*; and so steps had to be taken to protect shafts and other important installations in mines from the damaging effects of a mine's own excavations. Since the 1930s therefore, the planning of mining procedures near the shaft and of safety measures at the shaft itself, both designed to protect the structure from mining damage, were added to the responsibilities of subsidence engineering. One result was that a planned and economic recovery from among the large reserves of unworked mineral locked up in shaft pillars became possible for the first time.

Finally, subsidence engineering also has a safety role. Its measures in relation to both mining and construction help to protect communications networks, public utilities installations, important public buildings and historic monuments within mining areas from damage which could impair their functioning or even render them dangerous.

Subsidence engineering can be differentiated from the closely related field of *strata control* in the following way. In strata control, what is chiefly studied is stress changes and rupture processes in the immediate vicinity of underground excavations, with the object of minimizing convergence in mine roadways, avoiding rock bursts, sacrificing as little mineral as possible in support pillars, and utilizing rock pressure in the dislodging of mineral for extraction. It is thus the interaction between solid rock and roof supports or pillars in circumstances of disturbed load equilibrium which is at the centre of consideration in strata control (i.e., a load model). In subsidence engineering, on the other hand, what is principally being investigated is the interaction between loose ground and structural foundations or shaft linings under the influence of strata movements at a distance from underground workings (a movement model). The inclusion of strata control in the sphere of subsidence engineering as "subsidence engineering underground", which was still being advocated by O. Niemczyk in 1949 in his textbook on subsidence engineering, "Bergschadenkunde", cannot be sustained today in view of the very different legal position and practical objectives – leaving aside the common objectives of minimizing costs and preventing accidents – of the two disciplines. In the discussion which follows therefore the only thematic distinction drawn is between strata movements, triggered off by mining, in the interior of a predominantly solid rock body stretching from workings to caprock and shaft side (Part I), and on the other hand, movements in the loose ground of the upper surface layer in which surface structures have their foundations (Part II).

At the centre of the subsidence engineering stage stand the thickly populated coal-mining areas of Europe. Their numerous coal seams, often metres thick, are today mined across extensive areas 300 – 1000 metres underground, in fronts of 200 – 300 m length, without supporting pillars. The result is that the rock mass overlying them drops like a sagging plate behind the advancing coal-faces, immediately after extraction, and breaks up only on reaching the floor of the workings. The rock strata overlying massive orebodies and salt deposits subside in a similar way when mined, except that parts of these deposits, left standing like islands, often retard the progress of subsidence. Even in opencast mining, significant settlement and consequent damage can occur in ground adjoining a mine as a result of a fall in the water-table. Thus the ground movements, visible damage, and protective measures so familiar in relation to coal-mining are basic attributes also of other branches of mining – even of oil and natural gas production, which can lower the surface of the ground by a metre or more. It is only in the working of vein ore occurring in strong country rock that mining damage is negligible.

In today's active competition between domestic mining and foreign sources of energy and minerals, subsidence engineering is of mounting importance. More than ever is it becoming necessary to hold down the costs occasioned by mining damage – which average, for example, 6 – 8% of the per-ton cost of coal production – and to ensure the workability or reserves even under built-up areas. Mining subsidence engineering thus has a positive contribution to make to securing a competitive domestic supply of raw materials.

Part I Strata Movement

1. Strata Movement at the Mining Horizon

1.1 Mining Methods, from the Standpoint of Subsidence

The field of subsidence engineering stretches from the firm rock at the mining horizon to the surface layer of loose ground on which buildings stand and farming is conducted. The cavity artificially created underground by the extraction of mineral removes the natural support from the overlying strata. As a result, successive layers of rock over the mine workings bend under the influence of gravity, until finally the movement reaches the upper earth surface. At the same time, the underground cavity is closed up to a greater or lesser degree. The extent of movement in the upper layers thus depends on the closing up, over a period of time, of this cavity. The size of the latter is consequently the basic dimension in the calculation of strata and ground movement. By contrast, convergence between roof and floor in mine roadways plays only a minor part in movements occurring in the upper layers of overlying rock, because of the insignificant width of roadways.

Before the evolution of movement at the mining horizon can be discussed, it is first necessary to consider the various methods of winning mineral and to clarify certain mining concepts[1].

For the purposes of subsidence engineering, *mining methods* can best be classified according to the treatment of the roof and the degree of filling in mine excavations. By "roof" is meant the surface forming the upper limit of the mine excavation.

Roof treatment (control) can be differentiated into three categories (see Table 2):

a) Supporting the roof with pillars (stoping with *permanent pillars*). Parts of the deposit are left standing between the working fronts (the "stopes") to guard against movement of the overlying rock during mining, either because the rock is difficult to contain, or because it is water-bearing. This procedure of partial extraction is chiefly employed in mining massive deposits of salt minerals or metallic ores in firm wall rock. Long, parallel "pillars" are formed in the deposit by driving entry roads through it, which are then widened into "chambers" (chamber working, Fig. 1). In the case of high-value minerals, in order to limit losses of material to between 30% and 50%, only small, square pillars are left standing, by widening the entry roads into "rooms" or "stalls" and mining in strips on a grid pattern (*room-and-pillar working*, Fig. 2).

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[1] For geological concepts, see Figs. 35 and 48

Table 2. Classification of mining methods

Manner of working	Treatment of roof		
	With permanent pillars (partial extraction)	With filling[a]	With caving (total extraction)
In long fronts		Longwall mining (Fig. 3) Rill stoping Overhand stoping Underhand stoping	Longwall caving (Fig. 5)
In chambers	Chamber workings (Fig. 1) Room or stall workings (Fig. 2) Pillared open stopes	Room and temporary pillar Sublevel stoping (Fig.4)	Chamber working with caving Room-and-pillar with caving (Fig. 6) Open-stope caving (Fig. 7) Sublevel caving
In blocks			Block caving (Fig. 8)
In single faces		Bench stoping Overhand shrinkage stoping Cross-cut stoping	 Cross-cut stoping with caving

[a] In each case, with either simultaneous or subsequent filling ("stowing" in coal-mining)

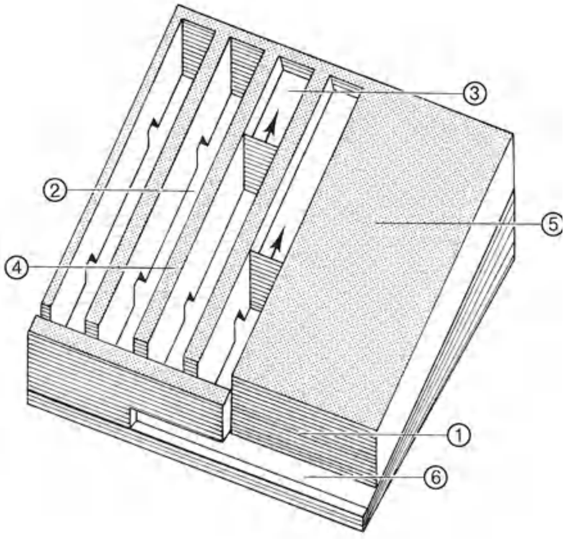

Fig. 1. Mining a massive deposit *1*, in chambers *2*, by breast-and-bench stoping *3*, between permanent pillars *4*. *5* Forefield (zone in front of face); *6* Haulage roadway

The pillars between chambers, rooms or stalls remain as a permanent and natural support for the roof strata, but they are liable to become gradually crushed later on by the weight of overlying rock. In salt-mining, for example, the final shape of the trough of subsidence at the surface often does not become apparent

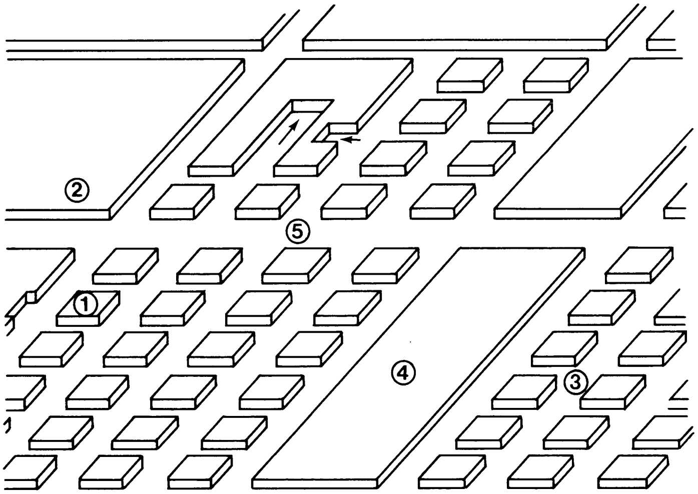

Fig. 2. Mining a flat-lying deposit *2*, by room *3* and regular, permanent pillar *1* working. *4* Barrier pillar; *5* main roadway

for a hundred years, i.e. not until the pillars of salt have finally been completely compressed. The extent to which the underground cavities have by then been filled depends on the volume of the pillars and chambers respectively. With room-and-pillar workings therefore, the subsidence engineer must bear in mind the long-term deformation behaviour, or rheology, of the rock mass, i.e. the time factor in relation to failure and flow criteria.

In a certain sense, the extraction of petroleum and natural gas from porous reservoir rocks can be regarded as "pillar working", because their supporting granular framework is left intact. Furthermore brining, which leaves undissolved supporting ribs of salt behind, can be included in this category.

b) Lowering the roof on to fresh support (*stowing*). In this procedure, the mine excavation is filled with crushed rock or other waste material to support the roof artificially in good time as it goes down, so that it will settle almost without a break. The stowing material will "give", but its support reduces the degree of sagging and of opening-up in the bonds between overlying layers. This technique is known as stowing and can be applied to room-and-pillar, longwall, and shortwall workings. For example, in mining extensive but relatively thin coal-seams by the longwall method, waste fill is introduced into the resulting 1 – 3 m high excavation as a supporting bed for the roof. This procedure is also followed in some other mining methods (see Table 2). The degree of filling achieved is around 50%, but with hydraulic stowing it can be as much as 80% or 90%.

Longwall mining (Fig. 3) is the method of total extraction principally employed in the European coal-mining industry. The *"long wall"* is the working face, which may be anything up to 300 m long and, depending on mining progress, may advance laterally towards the mine boundary by several metres a day. The narrow open strip, or "face working", between the "goaf" – the mined-out seam – and the coal-face is protected against roof falls by an array of vertical

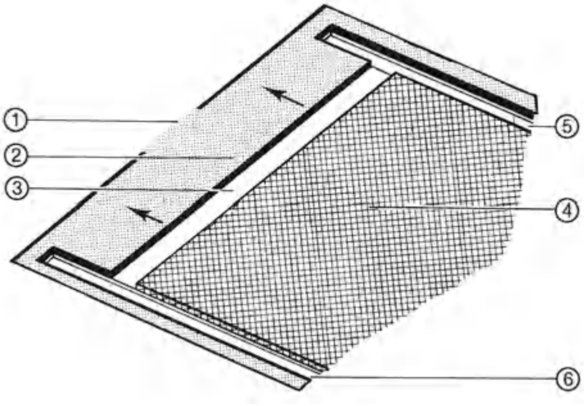

Fig. 3. Longwall mining of a flat-lying seam in direction of strike, with stowing or caving. *1* Forefield in seam (zone in front of working face); *2* extraction front; *3* face working, or face area; *4* mined-out area; *5* top road; *6* bottom road with conveyor belt

props capped with horizontal bars, or by composite supports having broader roof canopies. Mineral is both won from the face and transferred to the conveyor mechanically.

The newly mined and abandoned strip behind the face working must be filled immediately, and when mining makes good progress, perhaps advancing by as much as 5 m a day, this can present technical problems. The usual solution today is to employ pneumatic stowing, blowing in waste through special pipes. The "gate roads" leading on either side of the goaf to each end of the working face – the "top" and "bottom" road respectively – serve for ventilation, haulage, and manriding. In steeply dipping seams the working face is set at an angle to the gate roads to lessen the gradient.

Longwall mining is thus characterized by the long working front, the large area worked at a time, and the rapid extraction of the seam. The disturbed rock mass comes to rest again within 1 to 3 years of mining, leaving a flat trough at the surface.

Steep-dipping evaporite deposits are mined by sublevel stoping (Fig. 4). Intermediate ("sub") levels divide a deposit into horizontal slices, which are then blasted down from the bottom up, on an angled front. The steep, mined-out cavities thus formed are filled with residues from the related potash or other salt plant.

c) Caving the roof. In the *caving method*, the roof of the mined-out and abandoned working area is systematically caused to collapse, in order to avoid leaving large cavities with projecting slabs which could suddenly fall and endanger further working. The plan is that the immediate roof layer breaks off in large lumps and fills the mine excavation as a heap of rubble – a so-called self-stowing medium which provides a yielding underlay for the main mass of overlying rock. The latter then sags almost unbroken on to this and settles without subsidence delay directly behind the working front (see Fig. 5).

Because the immediate roof layers increase in bulk as they break up, the main body of overlying rock settling into the mined area subsides by only between 70% and 95% of the height M of the excavated cavity. The first segment of the roof ("I" in the Figure) collapses when the span of the open face-working reaches between 10 and 50 m.

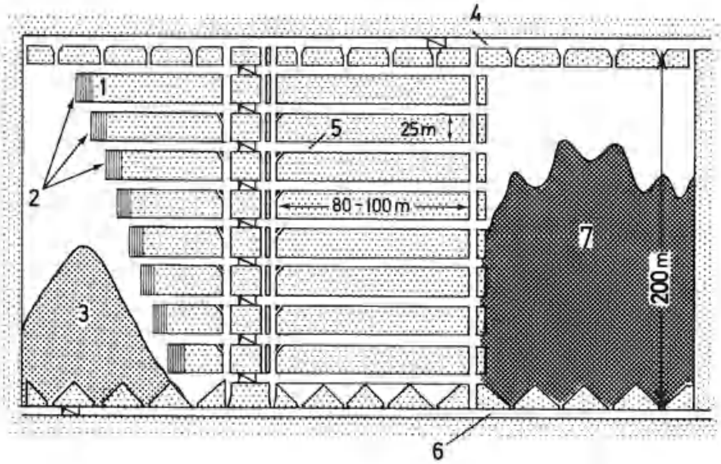

Fig. 4. Mining a steeply dipping, massive orebody or salt deposit by sublevel stoping, with filling (shown in vertical section). *1* Horizontal slices of deposit; *2* drill holes; *3* broken ore/salt brought down by shot-firing; *4* upper level (for bringing in waste fill); *5* sublevels; *6* main haulage level; *7* mined-out and filled cavity

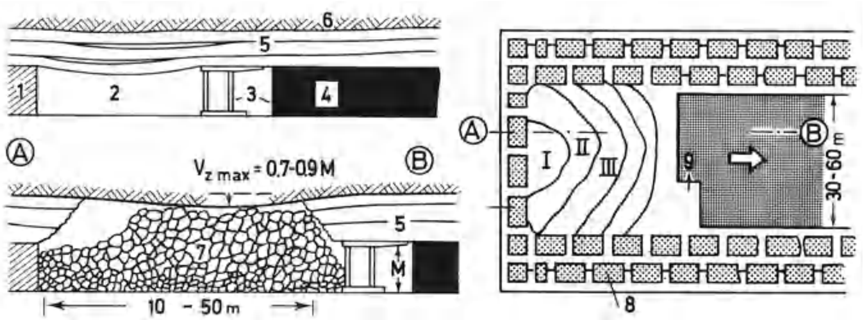

Fig. 5. Mining with caving, illustrated as a shortwall face (in plan *on right*, and in vertical section *A* – *B*, twice, *on left*. *1* and *8* barrier pillar; *2* open face-working; *3* coal-face and roof support; *4* seam; *5* immediate roof layers; *6* main roof layer, or roof rock; *7* roof layers, caved; *9* coal-getting with shuttle-car miner; *I*, *II*, *III* roof zones of progressive caving. (After L. J. Thomas, 1978)

Longwall mining comes within the category of caving methods if the overlying rock is such that it settles easily, and so also does room-and-pillar working in cases where, to save the cost of stowing, or to avoid sacrificing a proportion of the deposit, the pillars of mineral left standing between workings are ultimately mined. Figure 6 depicts a conventional procedure in U.S. coalmining, in which the pillars of coal, starting from the edges of the working panel, are systematically "robbed" without loss of mineral.

Two further methods which belong in this category are open-stope caving and block caving, both practised in ore mining. The first (Fig. 7), adopted in steep-dipping deposits having a certain minimum strength of wall rock, provides for an underground excavation, or "open stope", over 15 m high, from which the