Technological Innovation in Central Europe between the XIVth and the XVIIth Centuries

Danuta Molenda
Institute of History of Material Culture, Polish Academy of Sciences, Warsaw

1. Innovation and improvement in techniques form an important aspect of the wider process of technical progress and range from the adoption of new and more efficient machines and instruments and new methods of working to the use of new raw materials and new products. Changes in the organization of work that serve to rationalize and make more efficient the use of labour also constitute an important aspect of technical progress, albeit one that is frequently misunderstood if not completely neglected.

The discussion which follows is based on the example of technical development in the mineral ore and rock salt mining industries (we shall touch on metallurgy only to draw comparisons) in the area known commonly as Central-Eastern Europe — or more precisely, in Little Poland and Silesia (the areas on which my own research is based and for which I am most familiar with the sources), Bohemia, Hungarian Slovakia and Saxony. These territories constituted one of Europe's most important mining regions, and produced all non-ferrous metals that were known at the time (gold, silver, copper, lead and tin) as well as rock salt. The largest mining centres in Europe were to be found here and the industry had long historical roots while the scale of production was very large.

A period of considerable difficulty in the XIVth century had been caused by technical problems that proved impossible to overcome at the time, but this soon gave way to a new period of rapid expansion and development for the mineral ore and rock

salt mines. The expansion reached its peak in the late XVth century and continued through the first half of the XVIth century, although there were exceptions like that of Olkusz in Little Poland that reached its peak between 1550 and 1650. The expansion of the mining industries in this period was of course closely related to the more general development of the European economies, but the increasing demand for metal goods and salt in combination with favourable social, political and administrative factors all contributed to encourage the development of the mining and metal-working industries. Expansion in output was possible in part because considerable new mineral deposits were discovered, but above all because techniques were developed for mining at much greater depths than had been possible in the past. This in turn could only be achieved as a result of a wide range of innovations that made it possible to mine deposits that were lying in often inaccessible and dispersed positions below water level. Improvements in metal-working, on the other hand, also made it possible for the first time to smelt poorer quality ores and to use ores derived from rock forms that were difficult to work.

There is already a considerable amount of information available on the nature of the technical developments that were introduced in this period, and our knowledge has been greatly increased by the studies that have been published since the last war. The studies that were written to commemorate the quartercentenary of the death of Georgius Agricola in particular provide a detailed and comprehensive picture of the mining and metal-working techniques that were evolved in the region of the Erzgebirge mountains in the early XVIth century.[1] But there are

[1] Georgius Agricola. 1494-1555. Zu seinem 400. Todestag, Berlin 1955 / see the Studies by O. Fritzsche, by O. Wagenbreth on drainage, by H. Kirchberg on refining minerals/; O. Wagenbreth, "Bergbauliche Denkmale im Lichte der Bergbautechnik Agricolas", in *Freiberger Forschungshefte* D 18, Berlin 1957, pp. 90-126; H. Wilsdorf, "Agricolas Darlegungen und Illustrationen zum Thema Wetterführung und Wettermaschinen", in *Festschrift für Georg Fraustadt*, Dresden 1961, pp. 29-53;

many other studies of comparable developments in Bohemia, Silesia and Little Poland, although linguistic barriers mean that these are less well known.[2]

Since we already have a fairly detailed picture of the technical developments that occured in the mining and metal-working industries in this region from the XIVth to the XVIIth century, I shall only attempt to summarize the main developments in order to draw attention to the problems and topics that require further study. In particular I wish to concentrate on the ways and means by which new technologies and techniques were introduced in mining and metal-working, because these are the

idem, "Arbeit und Arbeitsgerät im sächsischen Erzbergbau des 16. Jahrhunderts", in *Deutsches Jahrbuch für Volkskunde*, 13, 1967, II, pp. 255-300. Many other studies had been published in the series *Freiberger Forschungshefte*.

[2] J. Kořan, "Těžné stroje ve staré Kutné Hoře" / Winding machines in ancient Kutna Hora/, in *Báňský obzor*, 1, 1947, pp. 49-52 87-91; idem, "Naše báňská technika za feudalismu" (Mining techniques in the feudal epoch), in *Sborník pro dějiny přírodních věd a techniky*, 2, 1955, pp. 5-52; J. Majer, "Jáchymovská důlní technika 16. a 17. století" / Mining techniqués at Jachymov in the XVIth and XVIIth centuriés/ , ibid., 12, 1967, pp. 137-164; idem, "Zur Entwicklung der Bergbautechnik des 16. Jahrhunderts im Westteil des böhmischen Erzgebirges", in *Deutsches Jahrbuch für Volkskunde*, 13, 1967, pp. 313-338; V. Lomič, "Důlni nástroje a jejich použiti ve středoevropských dolech v druhé polovině 16. století" / (Mining equipment and Machinery in Central European mines in the late XVIth century), in *Český lid*, 50, 1963; J. Vlachovič, "Technika dobývania, ťažby a úpravy rud v mediarskom podniku v Banskej Bystrici v 16.-18. storočie" / Techniques for mining transporting and refining copper ores on the Banka Bystrica mines from the XVIth to the XVIIIth centuries), in *Historické štúdie*, 7, 1961, pp. 5-30; J. Schenk, "Stoupy a jejich použití k drceni rud v českém a slovenském úpravnictví v XVI-XIX století" (Mills for crushing mineral ores in Bohemia and Slovakia from the XVIth to the XIXth centuries) in *Sborník pro dějiny...*, 4, 1958, pp. 161-194; many studies home also, appeared in *Studie z dějin hornictví* and *Zborník Slovenského banského múzea* / by J. Vozár, J. Gindl and others/; A. Keckowa, Zupy krakowskie w XVI-XVIII wieku / (The Cracow rock-salt mines from the XVIth to the XVIIIth centuries), Wroclaw-Warszawa-Kraków 1969; T. Dziekoński, Wydobywanie i metalurgia kruszców na Dolnym Ślasku od XIII do polowy XX wieku (Ore mining, and smelting in Lower Silesia from the XIIIth to the XXth centuries), Wroclaw-Warszawa-Kraków 1963; D. Molenda, Górnictwo kruszcowe na terenie złóz ślasko-krakowskich do polowy XVI wieku / (Mining mineral ore deposits in the Silesia and the Cracow region before the middle XVIth century), / Wroclaw-Warszawa-Kraców 1963; idem, Kopalnie rud olowiu na terenie złóz ślasko-krakowskich w XVI-XVIII wieku (The lead mines of the Silesia and Cracow region from the XVIth to the XVIIIth century), Wroclaw-Warszawa-Kraków-Gdańsk 1972.

aspects of the problem that have been least studied and which therefore still conceal the largest number of unanswered questions.

It was by no means the case that all branches of mining and metal-working experienced technical improvement at the same pace, and many branches of the industry remained virtually unchanged. Traditional methods and tools continued to be used for rock-cutting, for example, although it is possible to detect a steady process of specialization. But there was no major change in this field until gun-powder was used to blast rock, which was not until the early XVIIth century and even then on only a very small scale. The same was true for lighting and also for methods of haulage and horizontal transportation within the mine shafts. New types of wagons were developed, but there were very few mines that were equipped with rails or had extensive underground galleries that used wagons propelled by winches worked by men or horses like those that operated in the rocksalt mines at Wieliczka and Bochnia in Little Poland. Mechanical devices for ventilating the mine shafts also remained rare.

The most important and numerous innovations related to what was at the time the most critical feature of mining — vertical haulage and the removal of water. This was where the major technical problems that threatened to make continuous mining operation impossible were encountered. As a result, this was field in which the greatest technical ingenuity was shown and where technical innovation reached its highest points throughout these regions.

In general terms, the major changes related to the nature and size of the containers that were used to bring mineral ore, salt and water out of the mine shafts and to the cables, chains and pulleys that were used to work them. The basic mechanism was provided by the winch or winding gear, but its operation was continuously improved and expanded with the addition of better braking systems and the development of ever larger winches that were proportionately stronger (in Little Poland and Silesia

the horizontal wheels of the winding gear were often as much as 10 metres in diameter).

The removal of water was improved not only by the use of ever larger containers, but also by the development of new systems of wooden pipes (originally known as pater-nosters or *Heinzenkunst* and later as pumps). By installing such systems one above the other it was possible to reach the required depth. Important innovations were also made in the ways in which the raising and draining systems were powered, and manpower was gradually being replaced by draught-animals, especially horses. (In the salt mines near Cracow horses were even used underground, where they worked the gear that lifted the salt from the lower galleries). Those above ground were so large that they often required as many as thirty horses to drive them, each team working stints of between 6 to 8 hours in three or four shifts, twenty-four hours at a stretch. Another important innovation was the use of water power to drive the winding gear and drainage systems by means of the introduction of water-wheels - although these were found in only a handful of mines. Important changes also took place in the transmission of power between the drive unit and the extractive mechanism through the introduction of new systems of levers (*Stangenkunst*).

Other methods to remove water were used as well as the drainage shafts, and water channels were built in the galleries and the building of drainage galleries several kilometres long marked an important advance. In areas where the terrain was flat or provided little natural drainage, the two systems were often used in combination, using mechanical means to raise the water to the level of the drainage gallery. The building of longer and deeper mine shafts and galleries gave a new importance to surveying techniques and a major innovation lay in the introduction of detailed mine maps and plans which were in use at Freiberg and Kutna Hora in the early XVIth century.

The principal developments in metal-working involved the use of mechanical crushers to extract ore from rock, the addition

of substances that facilitated smelting and the adoption of new methods such as the famous *Saigerprozess* for separating silver and copper for example.

New mechanical instruments, new methods of mining and working the ores all constituted important aspects of the general process of technical progress and development. No less important, however, were the changes that were taking place in the organization of work. The size of the mines tended to grow much larger, and in place of tiny workings that scarcely covered more than a dozen square metres the mines often covered several hectares. This process of enlargement was closely related to, and was in many ways caused by the need to devise effective drainage systems, but it had important consequences and made possible a more rational organization of labour. The size of the workforce increased from a handful of workmen to ten, then twenty, and in some cases to several score and even several hundred. This was accompanied by a growing specialization and division of labour, and in the ore and salt mines in Little Poland the account books reveal that over 40 different categories of workers were employed in mining, transportation and drainage operations, and that the work was done by means of three eight hour shifts.

2. Although we have a good general knowledge of the technical changes that took place in mining between the XIVth and the XVIIth century, there are still many unanswered questions and many problems that merit closer study. I wish now to consider in particular those relating to the practical application of the new techniques and the ways in which they were brought into the process of production.

In order to evaluate the real impact of the innovations we need to understand not only their qualitative features but also their quantitative implications. In other words, we must try to ascertain to what extent the new methods and techniques were used in particular places to discover whether or not they worked

and also how frequently they were used and where. We must also discover how many mines continued to rely on older methods, which of the innovations were widely adopted and which, on the other hand, were used more sporadically. Such an analysis can only be done on the basis of the documents and sources on the mining industry in these regions that have survived. My own research on these sources suggests that despite the rate of technical development, very many of the mines in the principal centres of the industry continued to use older methods and techniques while the newer innovations were taken up in barely 10% of the mines, mainly because they were very costly. As a result, it would be extremely interesting to know what percentage of total production came from the 'modern' mines and what from the 'traditional' mines, but the nature of the sources makes this very difficult. But the information that they do contain does nonetheless provides us with the only basis on which to attempt to calculate the effective impact of technical innovation and to understand therefore the role of technical innovation in the process of production.

The new techniques and methods that we have described were not taken up uniformly either in every sector of the industry or in each of the different mining centres. In some cases innovations came early, in others late: in some cases they were taken up on a large scale, in others on a more partial basis. In the case of ore mining, for example, there were a number of what would today be called pilot centres which took the lead in developing and propagating innovations in both mining techniques and mining law. In the Middle Ages Kutna Hora was the leading mining centre in this part of Europe, while in the late XVth and early XVIth century the primacy moved to the Erzgebirge mountains in Saxony and subsequently to Bohemia.

The lack of uniformity can be explained in terms of a variety of different factors which inter-acted with one another. The nature and degree of technical difficulties was determined by the combination of prevailing geographical, geological and hydrog-

raphical conditions, by the quality of the mineral deposits and by the costs and profitability of extraction. Other important factors were the availability of capital for investment in improvements or new methods of production, and the degree to which the local political system provided legal and administrative institutions that favoured the development of the industry. But to see how these different factors worked in practice it is necessary to examine comparatively the developments that took place in different mining centres.

In the discussion that follows we shall attempt to set this in the context of what remains the most important single set of problems: the origins of technological development in this sector. To what extent did the technical innovations in mining derive from practice, from accumulated experience and from the practical application of that experience to new technical problems and difficulties that came to light? Or was it the product of more theoretical forms of knowledge that might have been acquired from the Renaissance onwards? To what extent were the technical solutions and improvements that were adopted in mining unique to that industry? Did they originate in the mining industry and then spread to other fields, or were they, on the other hand, derived in the first place from elsewhere — for example, from the irrigation techniques devised in agriculture, or from the hoists used in the building industry and which were, after all, a very traditional and indeed ancient form of technology? A recent study by Wolfgang Stromer, for example, contains a detailed description of mining technology and drainage in particular, and draws attention to the importance of the role played by Jewish technicians in communicating knowledge of techniques developed in the Islamic world and transferring these methods from the Mediterranean seaboard to the mines of Central Europe.[3]

[3] W. Stromer, "Wassernot und Wasserkünste im Bergbau des Mittelalters und der frühen Neuzeit", in *Der Anschnitt*, Beiheft 2: *Montanwirtschaft Mitteleuropas*

3. By what means were innovations adapted to the practical work of mining? How was knowledge of such innovations communicated? These questions still raise many uncertainties and doubts. Historians of the development of mining techniques have generally given such questions only secondary importance, although more recently they have begun to attract more serious attention.[4] Even so, the problems have generally been approached from the particular perspective of the protection of innovations and the development of laws on patents. In recent years these issues have been studied by Creutz, Öhlschlegel, Pohlmann, Silberstein and Zimmerman[5] as well as by a number of Polish authors,[6] and their research has made available much useful information as well as raising many interesting new questions. But I shall concentrate on certain aspects of these problems which have emerged directly from my own work on the records of the mining industries in this region and in this period.

vom 12. bis 17. Jahrhundert. Forschungsprobleme, éd. W. KROKER, E. WESTERMANN, Bochum 1984, pp. 50-72.

[4] Idem; cf. also: Ph. Braunstein, "Innovation in Mining and Metal Production in Europe in the Late Middle Ages", in *The Journal of European Economic History*, 12, 1983, pp. 573-591.

[5] H. J. CREUTZ, "Die Herausbildung des Erfindungschutzes in Sachsen im 15. und 16. Jahrhundert", in *Jahrbuch für Wirtschaftsgeschichte*, 1983, pp. 99-110; H. ÖHLSCHLEGEL, "Das Bergrecht als Ursprung des Patentrechts, Düsseldorf 1979; idem, Zur Entstehung des patentrechts aus dem Bergrecht in *Der Anschnitt*", 32, 1980, pp. 192-199; H. POHLMANN, "Neue Materialien zur Frühentwicklung des deutschen Erfinderschutzes im 16. Jahrhundert" in *Gewerblicher Rechtsschutz und Urheberrecht*, 62, 1960, pp. 272-281; P. A. ZIMMERMAN, "Frühe Beispiele aus der Welt der gewerblichen Eigentumsrechte", in ibid., 69, 1967, pp. 173-180; M. SILBERSTEIN, "Erfindungsschutz und merkantilistische Gewerbeprivilegien", Zürich 1961.

[6] S. SOLTYSIŃSKI, "Powstanie i rozwój prawnych form ochrony wynalazcy na przestrzeni XIV-XVIII w." / The origins and development of legislation to protect inventors from the XIVth to the XVIIIth century, in *Czasopismo prawno-historyczne*, 18, 1966, pp. 91-117; D. MOLENDA, "Patent a postep. W sprawie rozwoju prawa patentowego w górnictwie kruszcowym w XV i XVI w." / (Patents and progress. The development of patent right in ore mining the XVth to the XVIth centuries), in *Kwartalnik Historii Kultury Materialnej*, 17, 1969, pp. 73-88; J. WYROZUMSKI, "Zagadnienie początków prawnej ochrony wynalazku w Polsce" (The question of the origins of legal protection for inventions in Poland), in *Zeszyty Naukowe Universytetu Jagiellońskiego, Prace z wynalazczości i ochrony własności intelektualnej*, 18, 1978, pp. 17-34.

We must start by admitting that the sources give no indication of either the origins of the majority or the innovations that were adopted in individual mines or of how they arrived at a particular place. Such information can only be obtained in the case of innovations, or planned innovations, that were the subject of some written legal contract, agreement or concession. But these sources naturally refer only to certain types of innovation, by no means all and unfortunately not necessarily the most important. They are in fact merely the ones that have left the most tangible evidence of their existence. Notwithstanding that reservation, these legal sources still provide important information.

The sources that have been used come from a number of different types of documents. The first include the privileges or monopolies that were conceded to those who sought to develop and popularize new techniques, and which were similar to later patents. The second were proposals made to mining companies, to towns and rulers with mining interests. The third category cover agreements and contracts relating to the installation of new processes, sometimes with correspondence attached. The fourth group are made up of documents that contain descriptions of particular mines in which specific reference is made to new equipment or buildings, while the fifth consists of references to such installation drawn from legal proceedings, administrative documents and the account books of individual mines.

All these sources provide information on the timing of the improvements and the steps that accompanied their adoption. They tell us which mines were involved, give a general description of the proposed innovations as well as technical specifications, although these are generally rather vague. As a result we also know the names of those who built or installed new processes, while there is abundant information on the terms on which the work was carried out — the dues that were payable for the right to use the machinery, the share which the builders retained in future profits resulting from the improvement, and in many

cases the monopoly which they exercised over working the equipment and the prohibition of attempts to imitate or copy it. The terms were much the same throughout the area we have studied.

Albeit incomplete, the sources reveal that at least 150 new forms of machinery or equipment were installed between the XIVth and the XVIIth century (4% in the XIVth; 18% in the XVth; 64% in the XVIth (the majority before 1550); and 14% in the XVIIth century). In geographical terms, the largest number of innovations occurred in Saxony (in particular at Goslar and Schneeberg), in Bohemia (at Jihlava, Kutna Hora and Jachynov in particular) and at a slightly slower rate in central Slovakia (at Kremica, Banska Bystrica, Banska Stiavnica, Banska Bela). There were also numerous new works in Little Poland and Silesia, where mention is made of at least 50 new constructions.

These figures may simply be the result of using sources that have not been studied for other areas, and they may not therefore give a true picture of the rate at which innovations were being employed. There can be no doubt, nonetheless, that this region was extremely rich in technical innovations — even though little mention of this will be found in the standard texts. At Olkusz in Little Poland, for example, we have references to 19 new installations and of another 16 at Tarnowskie Góry (Tarnowitz) in Upper Silesia, both of which had important silver-bearing lead deposits. There were also seven new installations in the gold mines of Lower Silesia, and seven more in the rock-salt mines at Wieliczka and at Bochnia as well as in the salt-pans in the same region.

Of these 150 innovations, 90% were designed to improve the drainage of water from the mines, while 5% sought to improve transportation (although the latter was often an offshoot of the new drainage techniques). Other innovations were intended to improve the quality of the extracted mineral ores, of metalworking and salt refining processes. But these percentages show once again that removing water was the most serious technical

problem of the time, and it was here that the greatest efforts were made to find new and more effective solutions. The particular demands arising from the process of production dictated the prevalent pattern of innovation.

The pace of innovation was slowest in the XIVth century, although the earliest attempts to improve drainage techniques date from this time (at Jihlava, Goslar, the mining towns of central Slovakia and Meissen). But many areas were still able to mine relatively shallow deposits that lay above the water level, while those that went below it became flooded and were abandoned. The rate of innovation became much faster between the second half of the XVth century to the late XVIth century, and it was in this period that efforts were made on a really major scale to overcome the constraints posed by the water level because continuous drainage of the mine shafts had become a necessary condition for permanent mining.

In this period the rate of innovation was greatest in those regions where production was revived after a period of recession caused by problems of drainage (this was the case at Olkusz, Freiberg and Goslar), in those where mining was being undertaken for the first time (at Jachymov, Schneeberg, Tarnowskie Góry for example), or where the shafts quickly came up against the water-table posing drainage problems that needed to be overcome at once. The new techniques were in these cases overriding necessities.

Despite the fact that numerous innovations were introduced at both Tarnowskie Góry and Olkusz, after the 1560s these became much less frequent. Yet in the case of Olkusz we know that the late XVIth and early XVIIth century was nevertheless a period of particularly rapid development and that the mine shafts pierced well below the water-table, suggesting that once the techniques for removing water had been developed through the use of a combination of mechanical and gravitational devices no further need for technical innovation was felt.

Drainage was not always the primary technical problem, and

there were others that could assume the same role. At Zloty Stok (Reichenstein) in Lower Silesia, for example, five separate methods were attempted in the first half of the XVIth century to improve the quality of metal-making because the gold-bearing arsenic ore that was mined in the area was thinly dispersed in rock that was extremely difficult to smelt, which made the extraction of gold extremely difficult.

Neither was water a major problem in the rock-salt mines at Wieliczka and Bochnia. In the XVIth and XVIIth centuries the salt was mined at very great depths with shafts sunk to 100 and 150 metres, while many of the galleries were over 2 kilometres long. Here, on the other hand, the major problem was haulage to the surface and along the galleries and to overcome this very advanced technical solutions were adopted in both towns even though they remained unknown, or at least unused, in other European mining areas. But the techniques used were not protected by any franchise, as far as can be told from the documents, and there are references to only four proposals for further innovations between 1571 and 1583, none of which were important in technical terms. In this case it would appear that the improvements were the not the result of any major or single technical innovation, but of solutions that had evolved gradually in response to particular problems that had been resolved over time by means of steady improvements in old techniques and instruments which became more efficient and reliable.

4. I now wish to turn to those who introduced the innovations in mining. From the names recorded in the franchises and contracts that have survived it is possible to learn something about their background, their social positions and occupations, and of their role in launching new techniques.

The innovators acted either on their own account or in groups which normally took the form of partnerships. The sources from Kutna Hora and Schneeberg suggest that these individuals rarely originated from the areas in which they worked,

but came from elsewhere. This was also the case at Goslar, where we find reference to machine-builders from Prague, Magdeburg, Gotha, Leipzig, Bautzen, and Cracow. In the central Slovakian towns they came from Florence, Nuremberg, Danzig and Cracow, while at Kutna Hora and Jachymov there were machine-builders from Schneeberg, Stolberg, Erfurt and Italy and those at Schneeberg came from Nuremberg, Danzig, Zwickau and Dubrovnik (or Ragusa as it was then). In Little Poland and Silesia they came from the larger towns like Danzig, Cracow, and Wrocjaw as well as smaller towns like Biecz and Krosno — but there were many foreigners as well from Kutna Hora, Prague, Nuremberg and Wittenberg, from the Harz mountains and from even farther afield: Uppsala, Ragusa, Dublin, and Milan. They were nearly always natives of regions with close connections with either the trade in or the manufacture and mining of minerals and salt, with a marked predominance of those coming from major mining and metal - working centres.

The inventors and their partners came from many different social and occupational groups. These included those who had formerly worked in the administration of a mining concern, many specialists and technicians who were described in the documents as 'master-craftsmen', 'experts', 'artificers', and amongst this group there was also a goldsmith, a '*magister poncium*', a '*geomiter und astronomus*', a master mason, a miller from Little Poland as well as a joiner, a blacksmith and a carpenter. There were also members of the priesthood — a Benedictine from Ragusa, a monk from Uppsala, two Bohemian curates — many townsmen and merchants (especially those engaged in trade in metalwares and salt), noblemen from Little Poland, senior state officials (a royal Chancellor) and a senior churchman (a bishop).

The same individuals and partnerships often turned up in more than one place, either to offer their services or else at the invitation of mining companies or towns with mining interests. For example, a priest from Prague called Nicolaus de Havlick-

ovy Brod (Deutschbrod) worked in Bohemia, at Zlotoryja (Goldberg) in Lower Silesia, and at Olkusz and Goslar in the early XVth century. A Benedictine monk from Ragusa named Blasius worked at Olkusz and Schneeberg in the late XVth century, while in the same period the brothers Niclas and Hans Staude of Nuremberg were well known in Goslar and Olkusz, as was Petrus Felsan (or de Faltisheim) of Danzig. In the XVIth century many machine-builders who worked in Olkusz were also well-known in the neighbouring town of Tarnowskie Gory despite the fact that this lay across the border.

It is not easy to identify individuals who were responsible for the diffusion of particular innovations, mainly because of the problem of identifying the real inventor of any given innovation. Sometimes the machine-builder worked alone and in this case was named in the franchise and in contracts. In these cases the machine-builder was probably the inventor of the improvements that he was seeking to apply. This was the case of the two machine-builders who worked in Olkusz in the early XVth century and was the norm amongst the machine-builders working at Goslar in Saxony who like the Staude brothers signed their own contracts and either installed equipment at their own expense or in partnership with the mining companies that used the machinery.

Often the machine-builders did not have enough capital to meet the costs of construction, in which case they looked for partners and investors who would both finance the initiatives and also act as intermediaries to obtain favourable terms for the contractors. Such individuals might also help to solicit privileges and franchises from rulers. This occurred in Slovakia, and to a lesser extent at Schneeberg, but was particularly pronounced in Little Poland and in Silesia where the machine-builders were often recruited from artisans. But even amongst well-established machine-builders there was a preference for acting in partnership in this region, and well-known machine builders like Petrus Felsan and the Staude brothers who in other areas work-

ed on their own preferred to do so in partnership here. The Prague curate named Niclaus to whom we have already referred worked with five partners at Zlotoryja in Lower Silesia in 1404, whereas in a similar enterprise at Goslar in 1418 he had only two partners.

In the case of these partnerships it is extremely difficult to distinguish the real inventor from the other partners since there were very few contracts that named the builder and his business associates separately. There were occasions, however, when the builder was described as being without the necessary funds to carry out the work ('*sumptus non habente*'), with the explanation that his associates were therefore providing the requisite funds ('*sumptus proprios impendere*'). In some cases the contracts signed between the partners have also survived, and those relating to Little Poland include a contract between Petrus Felsan and a group from Cracow dated 1474, another between a miller named Jacobus Frolich and Johannes Kocwara, a citizen of Cracow, dated 1503, a further contract between Frolich and Kacper Ber of Cracow (1513), and a contract between two craftsmen and the chancellor Krzysztof Szydlowiecki dated 1528.

In general the contracts did not distinguish between the inventor and the investors, however, and all the partners were described indiscriminately as '*inventores*'. Unless the texts are read with care, therefore, they can give a very misleading impression. A good example of this — although there are many others — is provided by the reputation acquired by Johannes Turzon. Turzon was a citizen of Cracow, although originally from Levoca in Slovakia. He was a merchant and a financier who made large investments in mining and metal-working, and from 1495 onwards was a partner in the Fugger company. In the closing decades of the XVth century he was involved in introducing many innovations, financing the installation of new types of winding gear and new drainage systems as well as new smelting techniques at Olkusz, in Slovakia, at Goslar and in Hungary. As a re-

sult he has frequently been described by historians as the author of these innovations and as a leading inventor. But a closer examination of the sources quickly shows that the enterprises in which his partnerships were involved used the inventions made by master Petrus Felsan of Danzig (who has already been mentioned) and those of Kilian or Niclas Staude of Nuremberg. But the partners were also able to recruit other machine builders and the privileges and franchises that they received referred to the fact that the proposed work would be effected with the assistance of 'clever and skillful men' (*'viros peritos et ingeniosos'*) or else by 'such craftsmen and artificers as are suitable to perform such work' (*'per quicunquae magistros et artifices per ipsos ad id eligendos et conducendos'*). It should also be remembered that the partnerships included many other men who were very prominent in the commercial and financial affairs of Cracow in this period, such as Paulus Ber, Johannes Tegel, Seifrit Betman and Henricus Snellenberg from Thorn. Turzon was therefore only one amongst many entrepreneurs who took a particular interest in investing in new techniques and inventions, albeit he was particularly active in this field and undertook investments over a very wide field. Nonetheless it is important to set his contribution in the right perspective.[7]

The role of each of the partners in the different associations that were recorded in the contracts can only be established by a careful examination of the documents, bearing in mind the objectives of each partnership and its duration. This will require a thorough examination of all the written sources relating to mining innovations in this period. As a preliminary hypothesis, however, it seems that the individuals who were named in the contracts, franchises and other legal documents were the finan-

[7] See the recent Study by M. Skaladaný, Najstarši doklad o podnikatelskej činnosti Jána Thurzu v stredoslovenských banských mestách / The earliest sources on the activities of Johannes Turzon in the mining towns of Central Slovakia/, in *Historické štúdie*, 19, 1974, pp. 237-264; cf also D. Molenda, Górnictwo kruszcowe..., pp. 382-385; idem, Patent a postep..., p. 82.

ciers and supporters of the projects rather than the inventors or the machine-builders. Even when a machine-builder was himself one of the partners, his name was frequently eclipsed by his more powerful and influential economic partners. The investors were obviously concerned to secure for themselves the maximum profit from their investment, and it was their interests that determined and dictated the terms of the contract. The same interests were likely to be reflected in privileges or monopolies granted by rulers, and these were frequently granted specifically to the financial backers of a given innovation and either completely neglected the original inventor, or else simply accorded him a once-and-for-all payment while assigning the fruits of his invention to his financial supporters.

These backers were normally leading merchants, and although in Little Poland some clerics and noblemen also financed such ventures they never took a leading role. Investment in new methods for draining mines therefore provided an important channel by which commercial wealth was drawn into the mining industry in this period, and this in turn made possible the technical modernization of the mining industry and its remarkable expansion. The presence of investment companies of this type quickly became a characteristic of the mining industry in these years, and many of them undetook drainage operations on a regional basis moving from one mine to the next in turn. They were paid in cash and in kind, often being assigned part of the newly drained deposits, and in many cases also drew revenue from their own mines as well. The large and rapid profits which they made were often obtained at the expense of the mining concerns and the machine-builders, but their contribution to the dissemination of new techniques and to their practical application cannot be denied.

Together with the inventors and financiers, rulers also often acted as agent of technological development through the privileges and monopolies that they granted to those who wished to introduce new techniques in their lands. These privileges had

normally to be paid for, and in some cases gave the ruler a share in any resulting profits. When the privilege took the form of a patent it normally provided the inventor and his partners with additional benefits as well. Since much has been written about the reasons that led rulers to grant such privileges it is worth noting that the documents reveal clearly that there were a very wide range of motives that ranged from a conscious desire to protect the mining industry and to promote technical development to increase the revenues that derived from the mines to quite different considerations, such as the indebtedness of the ruler to one or more of the partners or, if the partners had powerful patrons, the desire to win new political supporters.

5. To what extent, if any, did the technical innovations that were occurring in the mining industry in this period bring real technical progress and greater productivity? We can only touch very briefly on this final issue, but many have doubted the practical effectiveness of most of the innovations. In many cases it is very difficult to establish exactly what a given improvement involved. The references in the sources are invariably very vague, and while they give a general idea of the type of construction proposed and the way it is to be built, they reveal little about the changes that it will bring about. The machine-builders generally limited themselves to promising that there would be a reduction in the demand for labour and hence in the number of horses required, an increase in the amount of ore extracted or water removed, and that investment costs would be lessened. In the case of metal-working it was also frequently claimed that the consumption of fuel would be reduced. It was always stated that the equipment was completely new and had never previously been employed, although in practice this meant only that it had not been used in that particular site: on other occasions reference was made to its successful employment elsewhere. As Wolfgang Stromer has also pointed out, many of the innovators offered to make improvements over a very wide range of opera-

tions at the same time, and made proposals for improvements in transportation and smelting as well as in drainage.

There is very little direct information on the practical effects of these innovations, and indirect sources for this are rare and fragmentary. This is true even for the XVth and XVIth centuries when the sources were much richer. Of the 12 innovations that Adolf Laube has documented for the Erzgebirge mountain region in the XVIth century, we know that three were failures although nothing is known about the other.[8] Of 8 innovations made at Goslar in the XVth century, we know that two were failures while there is only evidence that three fulfilled the hopes that were placed on them.[9] Jan Konan and Jini Majer have argued that the majority of the innovations that were attempted in Bohemia did not work in practice,[10] and in Little Poland and Silesia it also seems that the majority of the innovations recorded in the contracts and privileges never worked. Petrus Felsan's inventions proved unworkable at Olkusz, in Slovakia and at Schneeberg, and he was forced to flee from Danzig when the representatives of the mining companies attempted to force him to repay them. We also know that Frolich the miller had to mortgage his mill at Krosno to repay the money which Kacper Ber had lent him, and the enterprises of many other inventors ended in similar fashion. It was typical, however, that no matter how unsuccessful an inventor was in one region, he was still in demand elsewhere.

But a new clause began to appear in the contracts which stipulated that the machinery should be working and proven before the installer received payment. In Little Poland this stipulation was very strictly observed, and the period of 'trial' lasted from a few weeks to as much as a year.

[8] A. Laube, *Studien über den erzgebirgischen Silberbergbau von 1470 bis 1546*, Berlin 1974, pp. 118-122.

[9] U. Schmidt, *Die Bedeutung des Fremdkapitals im Goslarer Bergbau um 1500*, Goslar 1970, pp. 38-102.

[10] J. Kořan, *Těžne stroje...*, pp. 51-52, 87-88; J. Majer, *Zur Entwicklung...*, pp. 329-330.

How can these failures be explained? It seems that conscious fraud and deliberate attempts to deceive the mining companies were rare. The main cause of failure lay in the lack of technical expertise and ignorance of the elementary principles of engineering. This was why it frequently happened that machines which functioned well as models failed to work at all when installed in the mines. Too little account was taken of the different geographical, geological and hydrographical factors which might affect the performance of the machinery, so that machines that worked well in one mine proved useless in another or kept breaking down. It also happened that although after a while the new equipment could be made to work satisfactorily, it did not work any better than the old techniques which were often still much cheaper.

In cases where the innovation did not bring about an immediate and significant increase in profits, the payments owed by the mining companies became very burdensome. The companies frequently refused to pay, and in Little Poland the contracts began to include clauses which exonerated the mining companies from using the new machinery if they chose not do.

To summarize, it would appear that the real contribution of these innovations to production can only be established through a detailed examination of the different factors that lay behind the adoption and application of each innovation. Hasty and unsupported conclusions may therefore be misleading. It is essential to remember that by no means all the proposals made by inventors and machine-builders were actually taken up, and also that the reference to a specific innovation in a contract that has survived does not mean that the innovation ever worked in practice. Only a very small percentage of the large number of inventions and innovations referred to in the contracts, privileges and franchises can have made any effective contribution, therefore, to the modernization of mining and metal-working.

A more effective contribution to technical progress almost certainly came from the combined effects of the steady intro-

duction of new and better tools and machines and the better organization of labour — things that required no formal privileges or contracts, but underpinned a process of steady improvement. The principal agents of progress were the craftsmen working in each locality who were familiar with local circumstances. It may well have been that they also learned how to adapt some of those innovations that were in theory protected by patents and privileges, and to draw on new methods used in other places. The ceaseless migrations of the mineworkers in this period as they moved continually from mines that were being run down to those that were expanding must also have contributed to the accumulation of technical knowledge and experience. It was well known that the inhabitants of mining towns 'came from all over the world', as was noted in their municipal charters and chronicles, and this greatly facilitated the process of technical dissemination. For the same reason it becomes even more difficult to ascertain who first used a particular new method or piece of machinery or process of production and where. But ultimately this is less important than discovering where and when the major innovations were widely taken up and began to have a real effect on the development of mining. Fortunately, this is something which can more easily be demonstrated.