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Extraction minière souterraine plus sécuritaire grâce à la mécanisation? Le cas des mines d'or et de platine d'Afrique du Sud.

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Résumé

Les représentants des syndicats, des sociétés minières et de l'État sud-africain se sont formellement engagés à avoir recours à la technologie et à la mécanisation pour éliminer les risques pour la santé et la sécurité des mineurs. Les mines mécanisées sont plus sécuritaires que les mines traditionnelles puisqu'elles emploient moins de travailleurs. C'est particulièrement le cas pour le travail des parois rocheuses à l'aide de perforatrices portatives. L'histoire démontre cependant qu'en ce qui concerne les parois rocheuses des gisements étroits, ultra profonds et à basse teneur aurifère des mines d'or sud-africaines, les avancées technologiques ont été minimales depuis près d'un siècle. Même les gisements plus larges et nettement moins profonds des mines de platine souterraines se sont montrés résistants à la mécanisation, et seules les nouvelles mines ont introduit des technologies mécanisées à roues caoutchoutées sans rails, alimentées au diesel. Les perforatrices de roche portatives demeurent la norme technologique fonctionnelle dans les mines d'or et de platine souterraines, et n'ont que récemment été remplacées par des technologies mécanisées non-automatiques dans les rares filons larges ou massifs de très peu d'exploitations aurifères et d'un certain nombre de mines de platine. Bref, la mécanisation stagne dans les mines d'or et demeure limitée dans les mines de platine souterraines traditionnelles en place. Les trois principales causes en sont la géologie difficile des mines d'or et de platine, la résistance ancrée des mineurs et le peu d'empressement des gestionnaires des mines à tendance conservatrice. Le présent article étudie surtout la première de ces causes, mais traite aussi brièvement des deux autres motifs qui retardent la mécanisation des mines. En conclusion, l'article suggère que si les nouvelles mines ont adopté la mécanisation, cela risque peu de se produire avec les mines traditionnelles en place, qui sont de ce fait moins sécuritaires.

Safer Underground Mining via Mechanization? The case of South African gold and platinum mines.

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Abstract

Representatives of organized labour, mining capital and the South African state have formally committed themselves to use technology and mechanization to eliminate health and safety risks to mine workers. Mechanized mines are safer than conventional mines as they employ less workers. This applies especially to the rock face worked with hand held drills. The historical evidence, however, shows that technological advance at the rock face in the ultra-deep, low-grade, narrow ore-bodies of South African gold mines has been minimal for over a century. Even much shallower and less narrow ore bodies of underground platinum mines have proved resistant to mechanization with only new mines having introduced diesel-powered, rubber wheeled 'trackless' mechanized technologies. The hand-held rock drill remains the standard operating technology on both gold and underground platinum mines, only recently superseded by non-automated mechanized technologies in the rare wide or 'massive' reefs on a very few gold mines and a number of platinum mines. In short, mechanization remains stalled on gold mines and limited on established conventional underground platinum mines. The three main reasons for this are difficult geologies in gold and platinum mines, deep-seated worker resistance and managerial reluctance and conservatism. This article chiefly treats the first but also briefly discusses the two other reasons why mechanization has been impeded on these mines. The article concludes by suggesting that while mechanization has been achieved on new mines it is unlikely to come to full fruition on established conventional mines thereby making them safer as a result.

Introduction

In September 2008 key senior representatives of organized labour, capital and the state agreed to 'significantly improve the culture of health and safety across the mining sector' (MHSC, 2011:3). The Mine Health and Safety Council (MHSC), a statuary body, assumed primary responsibility for developing, formally constituting and ensuring the signing on 18 November 2011 of a broad-ranging guiding document - the Culture Transformation Framework (CTF). The third of eleven 'pillars against which the CTF is based' is technology. The CTF reads: 'We will adopt mechanization and technology as a key method of eliminating health and safety risk to mine employees' (MHSC, 2011:5).

The principle behind the idea that mechanization is safer than conventional mining is that fewer operators are exposed to 'the sharp end of the production face' (Harrison: 2008:293). Due to smaller numbers of rock drill operators and other workers at the rock face, as a leading advocate and practitioner of mechanization contends, mechanization *is* 'safer and more productive than conventional hand held drilling' (Pickering 2004:433). The long term aim appears to be completely mechanized mines achieved by fully remote controlled automated machines which dispenses with labour at the rock face entirely. Dr Jeanette McGill, head of Novel Mining Methods at the Council for Scientific and Industrial Research (CSIR) in South Africa, claims that 'we have a device that looks like a robotic crawler, that can work and manoeuvre over the underground rock and that we have the ability to put different sensors[2] on board that platform and to actually see what is happening underground. It is very exciting' (CNBC, 2014). It is, however, not clear what McGill means when she somewhat surprisingly claims that: 'Labour is excited, because the key drawback and advantage of this system is that we don't have to put people in the stope-face' (CNBC, 2014).[3] The hope that the 'robotic crawler' would 'happen' in two years does not appear to have been realized - potentially matching the disappointment attending a long series of attempts to mechanize the thin-veined narrow ore bodies of especially gold and also underground platinum mines in South Africa.

What this article does is focus on the key reason for stalled mechanization on South African mines, namely what Larry Lankton called 'the vagaries of geology' which, like gold and underground platinum mines in South Africa, 'hampered mechanization' on the

Lake Superior Copper mines (1983: 3). Here it is the low-grade of the ore-body, rather than the unique problems presented by the depth at which mining takes place, 3000 to below 4000m, which is the focus. The article also, but only briefly, notes the two other reasons - worker resistance and a conservative managerial culture - which have contributed to a long-standing reluctance to move away from the tried and tested technology of the hand-held rock drill.

In brief, the ore-bodies of the South African gold fields historically depended heavily on cheap labour to mine ore bodies which proved notoriously poor in grade and are exceptionally deep, yet have produced fabulous wealth due to their vast geological extent. These geological constraints to mining very narrow, ultra-deep reefs have proved formidable. This has not changed. Referring back to the earliest days of mining the academic literature noted a series of constraints facing South African mines: 'the low grade of the ore, the depth and unevenness of the reef, the hardness of the rock, the fixed price of gold, fluctuations in the costs of stores, and often militant white miners' unions' (Moodie with Ndatshe 1994:45). While the geological constraints remain, costs continue to rise, the gold price now fluctuates and new generations of workers have, since the 1980s and again since 2012 in particular, established powerful and militant black worker formations.

There are, in addition, but which cannot be addressed here, a series of *social* constraints regarding labour, a history of violence underground, political unrest and the way workers improvise in the labour process that have impacted on the technical capacity and hence the profitability of South African deep-level mining (See Moodie, 2014). In a comparison of mining in Canada, Zimbabwe and South Africa in the era of globalization the introduction of new technologies has further implicated, in increasingly similar ways, issues of wages, skills, team work and the mobility of labour (See Dansereau 2006).

Regarding mining technology in particular, thirty years ago the lack of profitability on South African gold mines was explained as due to only minimal underground mechanization (Richardson & van Helten,1982:85). At the time, mechanization was described as a 'hesitant revolution' (Frost, 1987:3) which only had limited success (Frost, 1990). Twenty years ago 'technical factors rather than the low level of wages' were cited as impeding capital-intensive mechanization on gold mines despite 'huge quantities of capital expended' (Fine and Rustomjee, 1996:90). Fifteen years ago the progress in mining technology between 1960 and 2000 was described as 'abysmal' (Christos, 2000:1). Significant developments in mechanization have since taken place. Yet regarding the stubborn heart of the gold mining labour process - the rock face in the working stope - equally significant challenges remain.

For over a century the hand-held rock drill has dominated the labour process in the geo-physical and socio-technical environment of South African gold mines. Investigations into mechanised stoping began in the early 1960s (Joughin, 1978), were implemented in trials in 1968 on one mine (Egerton, 2004) and the Stoping Technology Laboratory was established by the Chamber of Mines in the late 1970s. Despite this, there are today only a very few successful examples of mechanization in some stopes which replaces the hand-held rock drilling mining the narrow, thin-veined seams of ore bodies in ultra-deep gold mines. Only a very few gold mines as a whole, where very rare 'massive' reefs are found, have been partly or 'fully' mechanized - but even here this does not amount to automated production without human labour.[4]

Even in the much shallower platinum mines (below 400-1000m) in-stope mechanization has only occurred in the past fifteen years or so. Mechanization, developed in fits and starts and learning along the way, remains very largely limited to new platinum mining ventures and only recently appear to be taking root. To date, around twenty platinum mines have been partly or fully mechanized with diesel-powered 'trackless' technologies, generally squat, 'low-profile' load haul dumpers, mobile drill rigs and roof bolting machines. Regarding mechanization in general, a leading practitioner, Rod Pickering, described the current state of play in the following way: 'The assumption is that mechanization will be introduced to conventional mines and put miners out of work. The reality is that mechanization is being planned *exclusively* for new mines' (Gerhard, 2014:1) (My emphasis). From within the academy, Declan Vogt, who heads up Mechanised Mining Systems at the University of the Witwatersrand, was less emphatic[5].

Whatever the case regarding 'full' mechanization which refers to trackless technologies, this article discusses the reasons for effectively stalled mechanization in the gold mines of the Witwatersrand Basin and the Free State goldfields. It also notes, perhaps even more surprisingly, that mechanisation has only very recently gained traction on the platinum belt of the Bushveld Igneous Complex (BIC). It is worth noting that these two ore bodies are the largest known deposits of gold and platinum on the planet.

The introduction of any new mining technology is generally designed, not for safety but to increase efficiency, productivity and profitability (Hovis and Mouat, 1996). This is explicitly the case in South African mining (Bracher, van den Berg and von der Linden, 2003; Macfarlane, 2001; Kendal and Gericke, 2000). When attempting to realise these aims, mechanization of the rock face has encountered such complexity that the organisation of production has instead been the focus. Mechanization moreover occurs in a *social* context such that 'differences in the organisation of production from one country to another have as much to do with history and politics as with the nature of deposits (Dansereau 2006: 8). In fact, the extent of productivity improvements due to the organisation and reorganisation of production on South African mines, Suzanne Dansereau demonstrates, has been *masked* by the decline in the numbers of workers on these mines (Dansereau 2006: 10) (My emphasis).

In order to show some of this in the South African case what follow stakes Dunbar Moodie's discussion of the complex reasons accompanying the transition from hand to machine drilling as its starting point. It notes the historic trajectory of the hand-held rock drill and the rock drill operators' (RDOs) job at the heart of the mining labour process. The article further goes on to trace some of the engineering attempts to supersede hand-held machine technology which has been treated in greater detail elsewhere (See Stewart 2015). The article concludes by noting the two other reasons - worker resistance and a conservative managerial culture - noted above in mechanizing South African gold and platinum mines.

On a methodological note, the Association of Mine Managers' of South Africa (AMMSA) Papers and Discussions and the South African Institute of Mining and Metallurgy (SAIMM) proved to be an invaluable source for technical detail. The account is further supplemented with evidence from various other sources and my own, extended, practically-orientated research work employing a range of methodologies, including participant observation, across South African gold, platinum and coal mines.

On a technical note, the technology referred to in this article relates solely to *explosive* mining techniques. This important distinction has been applied in the very useful broad ranging comparison, alluded to above, of mining in Canada, South Africa and Zimbabwe (Dansereau 2006). As elsewhere, *non-explosive* mining techniques have demonstrably failed in hard rock South African mining conditions. It is worth quickly noting that in the 1970s, for instance, the hope was that non-explosive, *rock cutting* machines would carry the day regarding mechanization at the rock face of deep, thin veined, hard rock reefs on South African gold mines (Joughin, 1978). This endeavour never met with success - unlike on the highly mechanized cutting of coal since the 1920s on South African collieries and mines. Twenty years of subsequent research into attempts to develop non-explosive impact mining systems (i.e. rock cutting techniques) and finally implemented in full production trials in 1992, were discontinued in 1997 (Willis et al, 2004). Fifteen years ago, no non-explosive technologies had been expanded to mine wide use (Kendall and Gericke, 2000). This is still the case and applies globally - due to the far harder rock in gold mines. Ultra-high-pressure waterjet cutting the rock face underground remains at the experimental stage (See Gauert et al, 2013).

Of interest, however, is that the two key reasons for non-explosive, rock cutting not being suitable for South African mines mirror those already noted regarding implementing mechanized technologies. The first was the geo-technical environment. Non-explosive mining techniques relied on mining induced fractures in the rock, but on South African hard rock, thin-veined gold mines 'there were large areas of 'hard patches', that is where no areas of weakness existed' (Willis et al, 2004:119). Geological and technical reasons aside, Pat Willis went as far as to suggest the second reason was that 'much more importantly, human and organisational problems proved to be much more intractable' (Ibid).

In terms of the scope of this article, full 'truck and shovel' mechanization - which requires separate dedicated treatment - has been implemented on the wider reefs on the Igneous Bushveld Complex of the platinum belt which enables open cast mining, but is not discussed here.

The persistence of the hand-held rock drill

In order to mine at all, ore-bearing rock must be identified by exploration and assayed. After the sinking of mine shafts, the ore-body must be accessed by developing tunnels and haulages. The ore-bearing seams must be intersected and exposed. Rock must be broken in the stopes at the ore-bearing rock face and transported to surface. Critically, removing too greater a proportion of 'waste' (i.e non ore-bearing rock) in ore bodies with narrow seams 'dilutes' the precious metal content per ton, thereby potentially rendering the entire exercise 'unpayable' to use the local term, or which is, in other words, simply unprofitable. Hence, controlling the width of the stope (the distance between 'floor' and hanging wall or 'roof') is of primary importance (Pickering, 2004:431), whether on the very narrow seams in goldmines (from 250mm) or on the wider seams in platinum mines (from 800mm). This remains the case and also applies to the mining industry's hopes for the 'robotic crawler' noted above (CNBC, 2012).

Nearly four decades ago the mining engineering literature asserted that: 'For some years great emphasis has been placed on the mechanization of stoping methods as a fundamental means of improving efficiency' (Buckler, 1977: 1). Over two decades ago, the scholarly literature noted that: 'Indeed, despite an intensive search for new techniques, South African gold-mining stoping technology has changed little in its fundamentals' (Moodie, 1994:48). Today there is little respite for gold mines, while progress on new platinum mines is now finally underway.

The point is simply that the hand-held rock drill has been the most efficient technology to mine narrow seams on both gold and platinum mines. After a century of mining, it has been claimed: 'The match between current technology (i.e. hand-held drilling) and current stoping systems is near perfect' (Pickering, 2004:424). Not all mining engineers would agree. Nevertheless, the immediate social consequence is a large labour force required in the stopes at the rock face underground where the majority of mineworkers are located and who suffer the highest proportion of injuries and fatalities - hence the continued vision of safer mining via mechanizing work at the rock face.

The mechanization of hand-drilling

The introduction of the jackhammer rock drill - a 'light weight reciprocating rock drill' - has been dated to between 1905 and 1915 (Frost, 1987:6). It took over a decade, however, before the President of the Association of Mine Managers of South Africa (AMMSA) could say in 1917 that: 'Perhaps I may be accused of undue optimism, but I hazard the opinion that the jackhammer has come to stay' (Cited in Hocking, 1997:93). This statement was nothing short of prophetic. By 1918 rock drills (often referred to as machine drills) were used in all but 15% of stopes in the gold mines (Moodie with Ndatshe, 1994:50). The official history of AMMSA notes the later date of 1924 (Hocking, 1997:111).

The introduction of the rock drill was not uncontroversial. As noted, new technologies are not introduced into a social, political or historical vacuum. There were intense struggles between capital and labour centered around this major technological innovation (Moodie with Ndatshe 1994:46-53). Moodie goes on to suggest that: 'What might now seem to have been straightforward technological 'improvements' in mining methods sometimes did not seem so to management at the time because they affected workplace hegemony' (1994:46-7). Crucially, Moodie further states: 'New technologies and methods of work organization could become tactical weapons in the struggle to control the workplace' (1994:47). Such contestation aside, the introduction of the rock drill, as in the North American Western Mining industry, 'did not diminish the drillers' abilities or his need for physical strength (Hovis and Mouat 1996:440).

Moodie further points to the rationale for introducing the rock drill. These are similar to the reasons being given for mechanization on the platinum mines today (See Stewart, 2015). The shift from hand-drilling to the introduction of mechanized rock drills was due not to their technological superiority, but rather as a result of a shortage of labour at 'prices the mines were willing or able to pay' (Moodie with Ndatshe, 1994:50). The official history of the AMMSA concurs that a 'trend was [the] growing use of jackhammer drills in stoping, a result of labour shortages that made 'hammer boys' [hand drillers] an endangered species (Hocking, 1997:93). There were other factors, Moodie tells us, which influenced what was only the gradual introduction of rock drills: 'backlogs at other points of production, managers considering hand drilling to be safer and concessions to white miners' demands to maintain a higher ratio of black to white miners' (1994:53). The social and economic context, in this instance, powerfully impacted on whether the new hand-held rock drill technology was employed in the first place.

The technological advantage of the rock drill only properly asserted itself when mechanization occurred elsewhere in the labour process, namely after 'the introduction of the scraper winch in the

1930's (Moodie with Ndatshe, 1994:48), much like the 'gradual process', over thirty years, 'from hand to machine drilling' in the Northern American Western mining industry (Hovis and Mouat 1996:439). Since then, on South African gold mines, little has changed at the stope face itself, while on the new trackless mechanized platinum mines, much has changed as Suzanne Dansereau has shown both comparatively and more broadly (2006: 10-15).

To give some idea of the extent of the effect of the technological revolution for which the rock drill was responsible, in a modern stope, a rock drill operator can now drill around 60 shot holes to the depth of over a metre in a shift - as opposed to a single 24 inch (600mm) hand-drilled hole for which indentured Chinese workers were contracted just after the turn of the twentieth century (Kynoch, 2003:8) or the later 36 inch (900mm) hole required per shift (Richardson & van Helten, 1982; Moodie with Ndatshe, 1994) drilled by predominantly Mozambican rock drill operators from around 1910 until the early 1970s.

Improvements to the hand-held rock drill

Ever since the rock drill replaced hand drilling, it has not significantly been altered for over a century, though improvements have been made to enhance its capacity, and neither has the process of stoping has changed appreciably (Frost, 1987). An engineering report of a decade ago bears this out; neither alternative hole-making methods or the actual drill has received much attention (O'Brien *et al*, 2006). Research programs aimed at developing alternatives to blast-hole drilling itself nevertheless continue (Harper, 2004).

The technological focus - until very recently - remained the rock drill itself and improvements to it. The addition of a hydraulic air leg greatly facilitated its use (see O'Donovan, 1985:54). As ever, experimentation first took place around the length of the air-leg in the development ends (tunnels and haulages) and was then adapted to the narrower and more confined working spaces in the stopes (Fouche, 1956:425). Where air-legs were introduced to all the stope machines on a mine in 1954, additional holes were drilled per shift due to 'the reduced physical strain placed upon him [i.e. the rock driller]' as well as resulting in 'a faster rate of penetration' (Fouche, 1956:428). Rock drill operators no longer needed to hold the drill horizontally while exerting pressure on the drill either by the force of their legs or through the weight of their bodies.

In the wake of the Marikana strike at Lonmin in 2012, a news report astonishingly indicated that not all rock drills were fitted with an hydraulic air leg - a full forty years after a mining engineer expressed surprise that in the '1970's some drilling was still being carried out without the assistance of an air leg' (Pickering, 2004:423). One immediate social consequence of the air-leg, noted over nearly sixty years ago, was that, 'it has been found possible to use natives (sic) who would previously have been rejected on physical grounds as rock drill operators' (Fouche, 1956:428). In other words, the introduction of the air-leg meant that less physically strong workers could be employed as rock drillers, thereby making the pool from which workers could be employed in this critical occupation larger.

The introduction of the tungsten carbide drill bit, the significance of which is apparently disputed among mining engineers, but which both lasts longer and reduces the time spent changing bits, is another significant improvement to the drill. Besides these two technological improvements to the 'jack hammer' or rock drill, as well as the introduction of detachable drill bits, little else has changed over the past century. There is virtually only the sporadic use on some mines of electric hand-held drills and hydro-power technologies, neither of which has been generalized underground despite positive anecdotal reports regarding both innovations.

Attempts at mechanizing stoping

There is no systematic study on attempts to introduce mechanization in the stopes. This central activity in mining, occupies approximately half of a mine's workforce and is where 'the greatest improvements in overall productivity can be achieved' (van der Meulen & Harrison 1978:219). As noted, stoping is the process of removing as narrow a band of rock around the ore-bearing reef as possible. 'Stoping method and methodology ... is at the heart of the mining system (Pickering 1999:2). As Moodie indicates: 'The most difficult and labour-intensive part of South African gold mining is stoping' (1994:50). Hence the aim has long been to mechanize this central component of the labour process. For 'stoping technologies set the parameters for underground work on the South African gold mines' (Moodie,1994:50) as elsewhere.

Unable to replace the rock drill, the attempt to mechanize stoping focussed on the introduction of drill rigs and jigs with which much experimentation was associated. The early drill rigs did not replace the rock drill, but rather mounted the drill on a frame with guide rails - or rig - to enable them to slide across the rock face to different positions. The rig must first be set up - an additional task workers resisted. In 1968 a Chamber of Mines Research Organisation (Comro) report indicates that the attempt on one mine to introduce the drilling jig - which enables setting the direction of the drill - had been abandoned (Jensen 1968). Where drill rigs were reported to have achieved success on Stilfontein Gold Mine, their use was discontinued after the mine manager, Byron Christos, who introduced the drill rigs, left the mine in 1978 (Christos, 2000).[6] Over the years 'attempts to design and introduce effective rigs, jigs and hole directors' (Dicks 1978b:201) continued.

Where in 1975 the 'possibility of mechanizing stope drilling operations' was attempted, the reasons were clear: the drive to improve productivity and cutback on labour (van der Meulen & Harrison, 1978:219). Yet it was the attitude of white labour which was deemed partly responsible for the lack of success anticipated in introducing a stope drilling rig at Vaal Reefs in the late 1970's. Ken Dicks had a dim view of the white miners' lack of concern regarding a key aspect of their job - the accurate placement of the drill and the depth of the blast-hole to be drilled or what is referred to in the industry as 'drilling discipline'. 'The importance of drilling accurate holes in stoping, designed to produce maximum face advance per blast at the lowest possible width, appears to have had little impact on stoping personnel' (Dicks, 1982:254). The 'stoping personnel' Dicks is referring to here are the white miners. The white miners were simply not actively supervising the work of the black rock drill operators in the stopes at the rock face. White labour had in fact long since relinquished this key skill to black workers. Worse, what was discovered later was that 'it was often found that two fuses per hole were used [as recommended in the engineering design specification], but that the white miner's assistant - a black mineworker - only connected one fuse to the ignitor cord, thereby defeating the entire object of the two fuses' which was critical for the sequential blasting of the face (Dicks, 1982:255). Not only were white miners not supervising the actual work of gangs of black workers, but were further leaving their assistant to charge the face. To make matters even worse, social turmoil exacerbated the implementation of the drill rig. Ken Dicks' explained that:

'During 1975 the mine experienced severe labour unrest, with large numbers of Blacks returning to their homes and, because of socio-political changes, the pattern of labour to the mine was considerably altered. During the introductory period, 1976 to 1978, the turnover rate was high, but the impact of these changes on the system cannot be effectively gauged. The mobility rate, however, was definitely increased and this factor alone must have had a detrimental effect on the system' (1982:256).

It was not just the overall immediate social and political context which had an impact on the introduction of the drill rig at Vaal Reefs in the late 1970's. A more general point is made about white miners and their overriding concern with 'quantity rather than with the quality of production', an attitude born of 'mass mining methods' and not unique to South African mining (See Hovis and Mouat, 1996:434-5). Ken Dicks bemoaned the fact that:

'Many miners are more concerned about improving total output than about improving productivity. To them it is relatively unimportant that much of the work performed by Blacks is physically arduous. They believe it is incumbent on management to supply the trained Black labour to perform the tasks necessary in stoping (1982:257).

Not only miners, but shift bosses (now called shift overseers) explicitly expressed the same sentiment to me in the 2000's. They said they did not have time to train their crews of black mineworkers due to the pressures of production. The point is that while social relations and factors played a significant role in the unsuccessful introduction of drill rigs at Vaal Reefs at a time of social upheaval under apartheid, in changed social and political conditions over twenty years later under democracy while white supervisory miners and shift overseers continued to expect management to provide them with trained black workers, productivity (by way of concentrating on achieving low stope-widths and not simply total output) had become a focus.

In short, the weaknesses in introducing the drill rig were significantly due to social relations in the organization of production: High mobility rate of workers; resistance to change; incentives for workers; changes in senior management; administrative difficulties and communication problems (Dicks, 1982:259-260). More importantly, however, success lay in that the 'rig had to have a very clean face in which to operate and that the face should be as straight as possible' (Ibid). These two conditions for successfully installing drill rigs are hard (and sometimes impossible) to achieve and rely on considerable skill (blasting a consistently straight face) and worker dedication (keeping the stope footwall 'very clean').

Further attempts to introduce drill rigs in the 1990s, designed to facilitate and improve the productivity of rock drilling did not meet with the envisaged degree of success (Macfarlane, 2001). Despite hopes to the contrary, the introduction of a fully mechanized diesel-powered, low-profile electro-hydraulic drill rig suffered a similar fate, due not least to different reefs on which it was employed (Pickering, 2004). While there are some drill rigs to be found on some gold and platinum mines, they never appear to have found general acceptance. I have yet to observe the apparently 60 stope faces equipped with plastic rails (to overcome undulating footwalls), hydro-powered, twin-boom pneumatic drill rigs installed in one mine.[7] Most interestingly, the initiator of this mechanization project was Byron Christos - the mine manager at Stilfontein Gold Mine who implemented drill rigs there forty years ago!

Low stope width and in-stope mechanization.

Rare exceptions aside, the key reason for the stubborn persistence of the rock drill is not that it is a cheap technology, that cheap-labour working long hours was available under colonialism, segregation and apartheid in South Africa, but that human labour is highly flexible. Hand-held drilling permits the human rock drill operator to accurately trace and follow the narrow seams of ore-bearing reef in the stopes which machines have yet to accomplish. While under democracy rock drill operators have since 2012 won significant wage increases, they continue as ever to dominate work in the stopes in an autonomous fashion - and continue to work long hours which, like the drill they operate, have not meaningfully changed over a century.

The point is that tracing the narrow ore-bearing seams up or down dip, which are invariably uneven and 'steep' - generally running at a pitch of between 15 and 30º but which can climb to 70º- is a job which is not readily mechanized. Some insist mechanized cannot be 'retrofitted' into existing mines. Others privately claim the South African industry has simply not grasped the nettle of mechanization. To be sure, introducing mechanization in narrow reefs is complex.

Where mechanization in stoping *has* taken place, however, and is referred to in the engineering literature as 'mechanized stoping', this relates *only* to cleaning or scraping the stopes with winches - i.e. the removal of rock (Macfarlane, 2001; Corbett, 1968; Nott, 1960) - *not* the drilling of the rock face itself. Over fifty years ago, even regarding cleaning the stopes of broken ore, this generally applied to introducing new techniques, *not* the introduction of new technology (Nott, 1960:505). The high pressure water jet has of course replaced the shovel and which *is* an instance of mechanisation in the stopes. Yet even thirty years ago it was similarly asserted that no new technology is employed when conveyors were considered to move rock when the assumption was that 'mechanized rock breaking' was to be introduced (Buckmaster, 1976:43). The sharpening of drill bits and repair of the rock drills has, however, long been subject to forms of mechanization (Deacon, 1964).

On gold mines, due to wide stope-widths and 'dilution' of the grade of ore per ton of rock mined, the most extensive attempt at full mechanization at the rock face in gold mines - the Trackless Mechanised Mining Method, dubbed 'TM3' - in the late 1970's and early 1980's proved to be a disappointing failure (see Stewart, 2012). It was not the only one (Macfarlane, 2001). In-stope mechanization - 'mechanized rock-breaking - has only ever succeeded in rare instances defined by peculiar geologies of which the South Deep gold mine is clearly the most unusual (See Nite and Stewart, 2012:184-5), but which reports indicate remains beset with its own challenges and problems. It should perhaps be noted that the 'significant' advances in drill technology of the jumbo hydraulic Suzanne Dansereau discusses (2006:10) never took root at the stope face of South African gold and platinum mines.

On platinum mines, until around fifteen years ago, mechanization had patently failed to maintain low stope widths. It is clear, however, that 'extra' low profile, and 'ultra' low profile mechanized mining equipment, able to work in stope widths of 1,8m and 1,2m respectively, *have* in the past decade replaced rock drills on new mechanized platinum mines. In short, however, the hand-held rock drill remains the industry standard to mine low-grade ore at ever increasingly deep levels on gold mines and even at much lower, but rapidly deepening levels on platinum mines.

Reorganising stoping and the organisation of production underground

Given the general failure to mechanize stoping by meaningfully improving or replacing the rock drill, the aim had long been how to select the best stoping methods to match particular geological conditions and re-organize production accordingly. This implicates both the nature of the work and relations between workers and managers. Worker resistance to changes in work regimes is well documented in the mining engineering literature and the local mining industry has long been aware of this (Christos, 1976; de Bruyn, 1981). A conservative managerial culture and 'reluctance to change' from 'supervisory level through to the senior ranks within mining operations' has, for instance, also been cited as constraining mechanization (Engineering and Mining Journal, 2013:111). Where mechanization has been attempted, four of six factors cited by mining engineers as constraints to mechanization have explicitly been noted as "soft' factors (Willis et al, 2004) or what the industry widely refers to as the 'human factor'.

Instead of mechanization, work study techniques have been implemented to improve productivity and go back at least a generation (Solomon, 1978). In short, the consistent focus in South African mines has been the intensification and re-organization of work underground: breaking up large unskilled gangs, introducing team work and multi-tasking, replacing general miners with dedicated stope panel operators, closer supervision, improved training and attention to drilling discipline and stope width. It is these factors, all of which implicate both the social relations *in* and *of* production, as Burawoy taught us (1979), rather than mechanization which has consequently shaped work underground on conventional mines to ensure greater productivity and hence profitability.

That the re-organisation of production has been responsible for improvements in efficiencies and productivity, as noted in the work of Suzanne Dansereau above, is the fact that currently on gold mines ore-bodies of 4 grams of gold per ton of rock broken are being mined profitably - too low a head-grade to have previously been considered worth mining. The ore-grade on platinum mines is generally even lower. How is this being achieved? In brief, gold mining was only profitable if worked by mass mining methods.

Massive amounts of rock needed to be broken and moved by considerable numbers of low-waged labour spending long hours underground.

An overall objective articulated in the late 1970's has become a mantra often heard on the mines today - to perform a SQDB (safe quality daily blast). The aim of designing the cycle of operations in the stopes was 'to allow a blast per panel [stope] per day' and where 'each Black worker has clear and concise tasks to perform in a set daily sequence on the same panel' (Dicks, 1978:197). Yet it has subsequently been recognized that this is not always possible. Miners need more than one developed and well-equipped rock face at their disposal to achieve a blast a day. Within the industry much research has been conducted around these issues, the attempt, for instance, to establish the optimum target cycle frequencies of stoping requiring experimenting with different ways to mine and forms of organization the stoping workplace should assume, the arrangement and numbers of personnel being a key consideration (Lima dos Santos,1983).In this regard, teamwork and multi-skilling and/or multi-tasking has featured prominently (Phakathi,2002).

The aim of one documented experimental case of re-organising stoping was to shorten the length of the stope face which resulted in the improvement of 'face advance and productivity' 'for the same labour complement' (Knobbs, 1978: 247). Face advance, both in this instance and others - by similarly focussing on 'concentrated stoping operations' (Christos, 1976) - directly improved the labour productivity of both white miners and black labourers in a racialized context. An account of a productivity deal in 2005 in this journal - in which the rock drill operators were the central players - again showed the importance of face advance for the overall productivity of a mine (Stewart, 2012b). Such innovation and experimentation and considerable work done on improving risks and reducing hazards in mining in general and at the rock face in particular, is ceaseless and to which stope face workers must adapt.

A key social consequence of the persistence of the hand-held rock drill

As Larry Lankton showed applied to the rock drill operators of the Lake Superior copper mines, a peculiar status has long been attached to the occupation of those men who drill through hard rock (1991). In South Africa, whether they were the hand drilling Cornish craftsmen, the indentured Chinese workers or the Mozambican ‘hammer boys’ who replaced them or the current cohort of mainly migrant workers almost exclusively from Lesotho and the Eastern Cape,rock drill operators established themselves as something of an occupational elite (See Stewart, 2013). Only a very few women have entered their ranks (Benya, 2010). Initially highly skilled, their job has since then generally been deemed unskilled or at best semi-skilled. In the 1930’s and 1940’s rock drillers were considered to be ‘the kings of the mine (Moodie, 2005:561). Over seventy years later the same phrase was used as a criticism of their fierce expressions of occupational independence on the platinum mines. It has been argued that the rock drill operator- led strike wave on South African mines in 2012 cannot be fully appreciated without understanding the role of the rock drill operators and the persistence of the hand-held rock drill (Stewart, 2013). Despite advances in mechanization on the new platinum mines, the stubborn persistence of the rock drill carries with it a large number of rock drill operators who are here to stay for the immediate future. Mechanization of their job is not going to happen overnight.

Conclusion

There are then three reasons for the lack of technological advance at the rock face in gold mines. The first and by far the most important reason is geological; mining low-grade, uneven ore-bodies at exceptional depth has clearly been the major reason for limiting the technological development of the hand-held rock drill driven by direct human labour-power. Yet mining engineers have consistently pointed to worker resistance as a crucial reason for the failure of attempts to introduce technological improvements at the rock face. Managerial reluctance and conservatism, generally only privately acknowledged and regarding which no study has yet been made, has also been held to have been a brake on technological innovation. Interestingly, this is the key reason for the lack of mechanization for Byron Christos - who has been plugging away at developing the mechanized drill rig for forty years! Worker resistance and a conservative managerial culture have then also played their part, both issues being worthy of dedicated attention.

The point is that the early industrial technology of the hand-held machine rock drill has proved to be the most efficient, tried and tested technology to mine narrow seams of ore-bearing reef on both gold and platinum mines. With the rock drill not having been readily replaceable, underground mine work has become increasingly intensified *without* the employment of mechanized technologies which is the usual route for facilitating and advancing capital and labour productivity. In other words, maintaining large numbers of 'semi-skilled' rock drill operators and their attendant crews of subsidiary workers at the rock faces seem highly likely to be continued on gold mines and on existing platinum mines. While mechanized twin-boom drilling rigs *reduces* the number of workers at the face, it does not *remove* workers from the rock face, but there appears little appetite at a managerial level to introduce them widely at this point.

Simply expressed, much of the South African mining industry continues to rely heavily at its productive heart on massive tranches of the expenditure of human labour-power (measured in hours and long working days) using a hand-held, compressed-air-powered and water-cooled rock drill. Workers have resisted changing from the hand-held technology they directly control and know best in dangerous conditions at the rock face underground. Despite extensive experimentation and even successful projects which promised great hope for mechanization, mine managers and mining engineers, it appears, similarly remain locked into their traditional conservative managerial culture. To hazard a prediction, underground mining on existing gold and platinum mines is not about to become safer by *removing* workers from the rock face via mechanization.

Endnotes

1. Sociology, University of the Witwatersrand, South Africa, Paul.Stewart@wits.ac.za.
2. The use of computerized sensors on mechanized equipment goes back at least a decade (See Dansareu, 2006).
3. The stope is where the production cycle of supporting the hanging wall (the roof), drilling and blasting the rock face and removing the broken rock takes place.
4. South Deep is the world's first fully mechanized deep-level gold mine' (Mining Weekly Online, 8 Dec 2012). The ore-body of this mine is an unprecedented 30m tall as opposed to thin-veined ore-bodies of 250 mm at deep levels on the Carbon leader reefs. By all anecdotal accounts mechanization has not proceeded smoothly.
5. Personal communication, 20 August 2015.

6. The information in the published interview with Byron Christos was supplemented by personal communication, 26 August 2015.
7. Ibid.

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