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A MODEL OF COALFIELD DEVELOPMENT: SIX STAGES EXEMPLIFIED BY THE SYDNEY FIELD

A six-stage model of coalfield development is presented. It portrays the typical or natural sequence of coal exploitation, which primarily takes place underground, and illustrates the sequence of transport and settlement development on the surface. Stages in the model relate to the exploitation of increasingly remote reserves, a process governed by changing mining technologies. While the model is presented for a simple plain, variants for coastal fields and fields with indented topography are introduced. The Sydney coalfield of Cape Breton demonstrates the utility of the model in providing an explanatory framework for an otherwise complex and confusing chain of events.

On présente un modèle, de six étapes, du développement d'un bassin houiller. Le modèle démontre la séquence typique ou naturelle de l'exploitation du charbon, qui s'effectue principalement sous terre, et illustre aussi les développements sur la surface dans le transport et dans l'urbanisation. Les étapes dans le modèle sont reliées à l'exploitation de reserves qui sont de plus en plus éloignées, et qui s'exploitent grâce aux changements dans la technologie minière. Le modèle présente le cas d'une surface uniforme, mais fait également part de certaines variantes se rapportant à des bassins côtiers et à des bassins situés en terrain accidenté. Le bassin houiller de Sydney, au Cap Breton, démontre l'utilité de ce modèle, en présentant un cadre explicatif d'une série d'événements qui seraient par ailleurs complexes et confus.

Coal powered the industrial revolution. The exploitation of coal resources played a key role in shaping patterns of regional development in the last century, and the residual effects of that development remain important today. Of particular concern are problems relating to the closure of mines in certain areas, with all that implies for economic and demographic decline, and the opening of new mines in other areas, with attendant problems of environmental and social disruption.[1] It is clearly of importance to understand the sequence of coalfield development, and to identify general factors moulding the changing location and intensity of mining activity, and the changing size and economic health of mining communities.

This paper outlines a general six-stage model of coalfield development, analogous to Aschmann's 'natural history' for a single mine.[2] The model portrays, for each stage, the location, type, size, and spacing of collieries, and changes to the settlement system and transport network. The stages refer to a three-dimensional sequence of coal exploitation, strongly controlled by changing technologies of mining and transport. As such, they represent similar, but by no means identical, time periods on different coalfields. Indeed, the same coalfield may demonstrate several stages of the exploitation sequence at the same time, while coalfields developed recently may omit the first four stages altogether. The model was developed inductively from a study of the historical geography of the Sydney coalfield of Cape Breton Island, Nova Scotia,[3] but has been extensively simplified and generalized through reference to work on the historical geography of other coalfields,[4] and to the literature on mining technology.[5] While every coalfield has a specific geologic and topographic structure, and the pace and pattern of development are frequently modified by details of leasing and company

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organization, there are sufficient similarities and generally operative processes to make a general model both appropriate and useful.

The only general spatial model of coalfield development currently available is Wilson's 'evolutionary' model, derived inductively from work on the fields of New South Wales.[6] This model is readily understandable, but too simplistic in that it posits only one commercial seam, and a single market or distribution centre. No coalfield of any size has only one commercial seam, and most fields eventually become major markets for their own product. Wilson's model is also problematical in being essentially non-historical. The phases in the model represent a locational sequence without reference to the era in which that sequence is occurring. Thus, the model fails to incorporate the effects of changes in mine and transport technology through time, and suggests that mines in succeeding phases exploit similarly sized holdings, and are of the same general scale. As the development sequence on the Sydney field shows, technologies available at any one time place strict limits on economically exploitable reserves, so that periodically those limits must be circumvented by the introduction of new technology. Investment requirements for new technology are the major reason for increases in the scale of both the mines and the companies operating them, and increased mine size in turn produces changes in the scale and spacing of colliery towns.[7]

The Sydney Coalfield

Cape Breton's Sydney field has been exploited over a longer period than any other in North America, and is the only Canadian field to have experienced all six stages of exploitation, from rudimentary quarry to supermine. For this reason alone, it is the best Canadian candidate for exemplification of the model outlined below. In addition, however, the field possesses several advantages as a case study. Its topography and geology are relatively simple, and approximate the model in that no more than three seams have been worked commercially at any location. The area was virtually unsettled prior to the development of mining, and its economy and settlement system grew almost solely in response to mining.[8] For most of its history, the Sydney coalfield was the largest in Canada, in terms of both production and employment, so that mining operations were at a significant scale in all stages of exploitation.[9] The succession of leasing arrangements, and the changing organization of coal companies, have been fairly typical of older coalfields, and are very well documented.[10]

The Sydney field, however, differs from the typical case in one major respect – it is a coastal field, with only a portion of the seam outcrops onshore. While the sequence of coal exploitation has been fashioned by the same set of technological limitations and opportunities as in the 'simple basin' model, the special problems of a submarine field produce different patterns and sequences on the surface, with respect to mine size and longevity and to the size and economic fortunes of the colliery towns. A modified version of the model is necessary to fit this case, and the opportunity is taken here to produce modified versions for other topographic cases (for valleys tranverse and parallel to outcrops).

A brief description of the Sydney field's geology follows.[11] The coal measures outcrop roughly parallel to the coast along a 60-km stretch from Cape Dauphin to Cape Morien. The continuity of the crops is broken by inlets of the sea, notably Sydney Harbour, and by anticlines which bend them seawards (for example, the Cap Percé anticline, which separates the Morien coal basin from the Glace Bay basin; see Figure 1). Seams are gently folded, with few faults, and dip NNE at a generalized angle of six to seven degrees.

Figure 1 shows those seams that have been worked commercially. The lowest, which outcrop furthest inland, tend also to be the thinnest. The three most important seams commercially are the Phalen, Harbour, and Hub. Of these, the Phalen is the lowest and therefore underlies the greatest landward area. It is generally 150 to 250 cm thick on the South Side, but splits into several marginal seams north of the harbour. The Harbour seam exceeds 125 cm in all areas except Boularderie Island (west of the Little Bras d'Or), where it splits and averages only 90 cm. The thick Hub seam outcrops primarily offshore, so that its presence at Table Head near Glace Bay is especially important. This seam thins in the New Waterford area and splits on the North Side, but reunites to form a 250-cm seam on Boularderie Island, known locally as the Stubbart.

In the following discussion, the Sydney field is used to exemplify each stage in the coalfield development sequence. Due to the complexity of actual events, and the

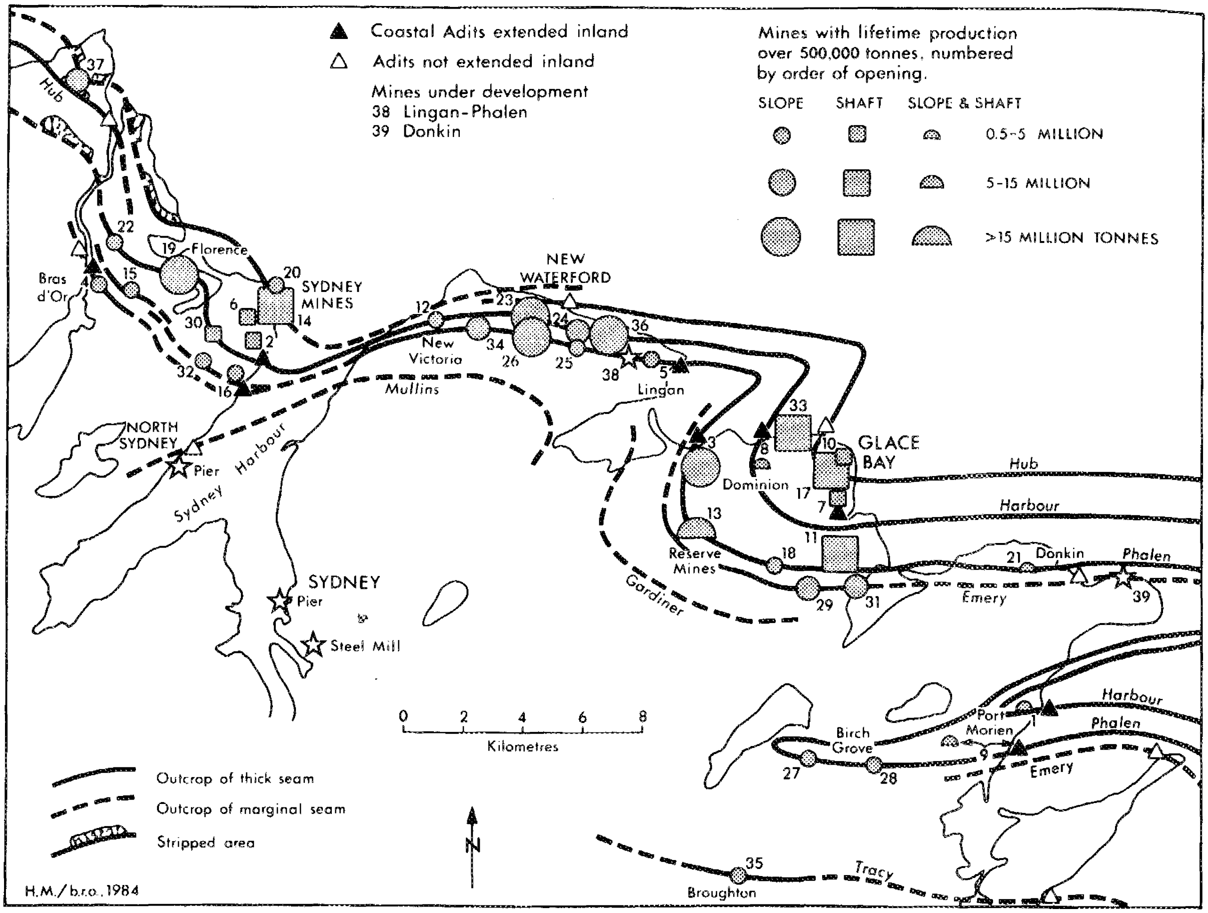

Figure 1
The Sydney coalfield, showing outcrops of important seams and major mines

number of mines involved, no attempt is made to present a complete historical account, but rather representative examples are provided.

STAGE 1: QUARRIES, ADITS, AND INGOING EYES

General: Consider a hypothetical coal basin with only three workable seams, dipping gently westwards from their outcrops (Figure 2). The upper and lower seams (A and C respectively) are generally marginal in width, while the central seam is consistently thick.[12] In the early stages of coalfield exploitation, the market or shipping point is located off the field. Assuming that development starts early (say, prior to 1800), then initial mining activity commences very close to the market (accessibility being a more important consideration than seam width) and is rudimentary in character. Coal is simply quarried from cliffs or river banks wherever seam outcrops are exposed and wherever there is easy access to a market. Once simple quarrying exhausts the exposure, 'ingoing eyes' (short tunnels or drifts) may follow the dip of the seam into the bank, but their length is severely limited by lack of roof support or drainage. Alternatively, wherever possible, short adits or levels are driven along the strike of the seam, draining the coal lying to the rise by gravity; but cave-ins and lack of ventilation limit these to about 100 m in length. Bell-pits are used to work areas of the seam to the dip of the crop, but their depth is limited to 10–15 m by reliance on buckets or a man-powered windlass for drainage. A

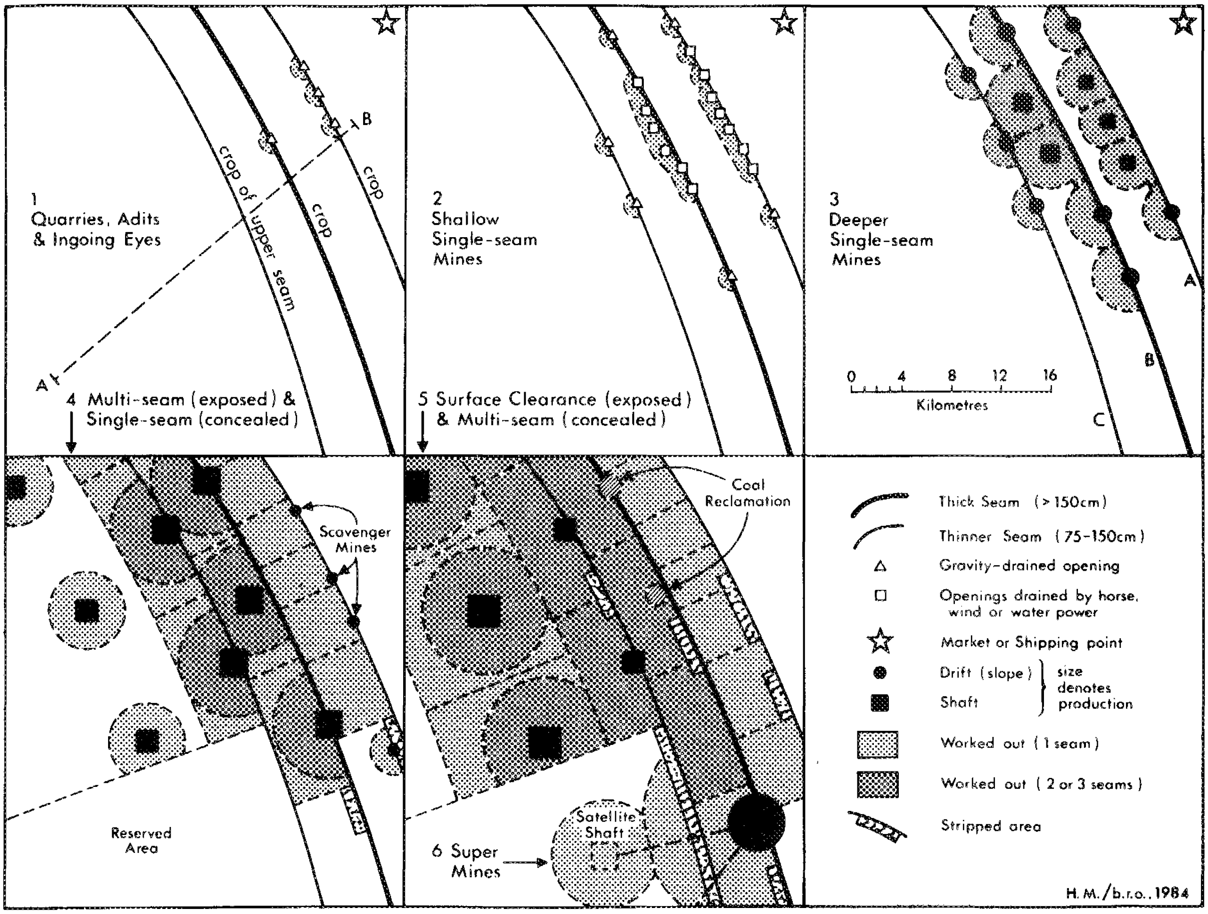

Figure 2
The coal exploitation sequence for a simple coal basin

typical mine produces under 1,000 tonnes per year. Stage 1 methods were of importance on European fields only until the early 1700s, though they are used throughout the world even today, particularly in 'bootleg' or 'coal-smuggling' operations.

While little coal is accessible by these methods, the main technological deficiency in stage 1 relates to surface transport. Langton[13] quotes coal as more than doubling in price over a five-mile journey in the early eighteenth century, since it was carried by cart or even pack-horses over very poor roads (Figure 3). Coal was therefore exploited on the coast or navigable waterways (a locational preference reinforced by the need for gravity drainage), and inland fields hardly developed until the canal era.

The Sydney field: On this field, the majority of output up to 1790 was gained by stage 1 methods. Seam exposures in cliffs were first exploited by French and New England colonists taking loose coal from the base, or digging into the cliff with crowbars and shovels, and loading directly onto their boats.[14] This practice was common from about 1670 to at least 1795, but was irregular, unregulated, and known as coal-smuggling. The first organized workings were begun by the French in 1720 on a 270-cm exposure on Morien Bay: the adits of this 'French Mine' (No. 1 on Figure 1) intially supplied fortress Louisbourg, but were continued by the British military until 1825. The latter also opened an adit at Burnt Head (on the Hub seam north of Glace Bay), but the major government operation was located in 1784 by

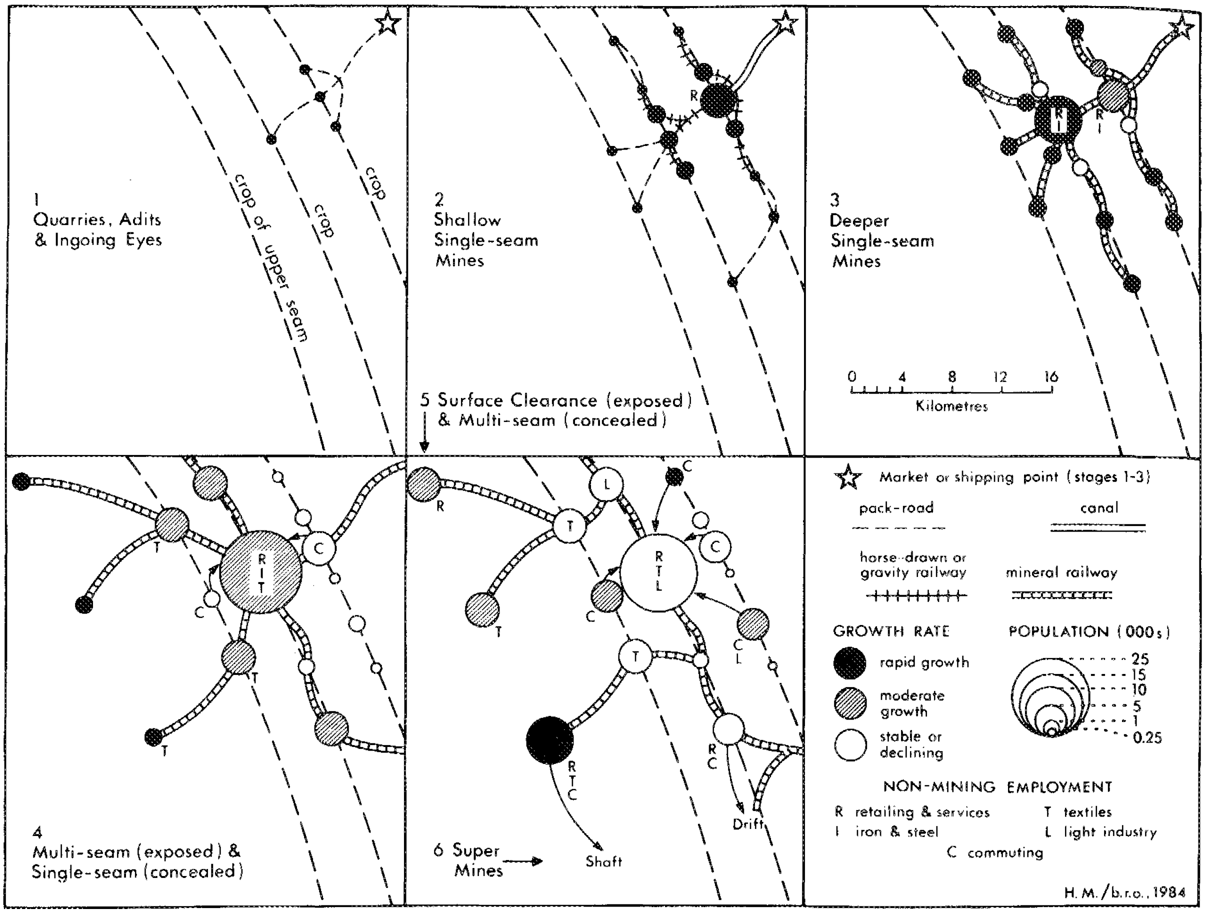

Figure 3
The sequence of transport and settlement development for a simple coal basin

Governor DesBarres at a sheltered seam on Sydney Harbour, where coal could be loaded directly onto a wharf (No. 2). Since the government owned a monopoly on coal, no further adits were opened legally until, by an unusual train of events, that monopoly was leased in 1826 to an English company known as the General Mining Association (GMA). Between 1829 and 1855 the GMA opened new adits at 'conspicuous' exposures of the thick Phalen seam (Old Bridgeport, 3; Old Lingan, 5) and at cliffside exposures of the Hub and Collins seams along the navigable channel of the Little Bras d'Or.

After 1858, the GMA surrendered many of its lease areas, particularly on the South Side. Mining licence areas, each of one square mile (2.6 km^2), were purchased by local speculators, who were confined by their lack of capital to operations of the stage 1 type. As examples, Mr Archibald opened an adit at the mouth of Renwick Brook at Glace Bay (7), and Messrs Cadougan and McLeod worked a cliffside exposure of the Harbour seam (the Union Mines, 8). Mr Bourinot drove a level through the old French workings (1, renamed the Blockhouse mine), and Messrs Archibald opened an adit on the Phalen seam a little to the south (the Gowrie mine, 9).

STAGE 2: SHALLOW SINGLE-SEAM MINES

General: This stage sees a continuation of stage 1 workings further from the mine opening and deeper into the ground, so that it applies initially to the more accessible and more exploited portions of the field (see Figure 2). Though mines in this stage lack steam-power, several technological innovations are introduced to overcome drainage, ventilation, and roof-support problems, allowing mines to reach 50 m in depth, and workings to proceed up to 200 m from the nearest shaft. Gravity or free-course drainage is still employed wherever possible, but adits (also called soughs) are now constructed scientifically to drain extensive areas. Elsewhere shafts are sunk to a sump-point: levels driven along the strike of the seam from this point drain all coal lying to the rise, and the sump is drained by horse-drawn windlass or water-wheel engine. Coal is no longer simply tunnelled into, but worked methodically by the room-and-pillar (bord-and-stoop) method in the drained land between the level and crop. The rooms are a rectangular lattice of passages advanced in the coal, while the pillars are the remaining blocks, left to support the roof.

Many mines in stage 2 are still ventilated naturally, with shallow pits for air, man-access, and coal winding sunk to the level every 100–200 m, as mining progresses parallel to the crop. Where workings proceed under hillsides, however (see the valley variants on Figure 4), air has to be forced (by bellows) or drawn (by a furnace) to the working areas through pipes. Since mines are now larger (typically 10,000 tonnes per year, and employing 100 or more), underground haulage and coal-winding become crucial constraints on production; the former is improved by the gradual introduction of underground wagonways and pit ponies (superseding human bearers), and the latter by horse-gins (superseding ladders or hand-drawn windlass).

Surface transport also improves in this period, particularly for inland fields, which are opened up by canals. On coastal fields, larger wharfs and sheltered harbours are developed to handle increased output. As mines progress inland (or away from the canal-head) short wagonways are constructed, and pack roads are improved by planking or paving. These improvements are suggested on Figure 3, as is the rapid growth of settlement produced by a ten-fold increase in employment. Colliery villages are still unplanned, spontaneous, and amorphous, but there is sufficient population to engender a retailing or market function at the more central of these.

The Sydney field: Stage 2 was characterized by inland extension of certain adits opened during stage 1, particularly those on thicker seams and adjacent to suitable shipping points. Most of the coal dug between 1784 and 1829 came from the DesBarres mine, or Sydney Old Works, which was operated by a succession of lessees who could neither afford nor maintain a steam-engine for drainage. Rather than working deeper coal nearshore, therefore, they extended their adit inland, draining a 150-m band of coal between high-water and the crop. A series of shallow shafts was sunk every 200 m for access, winding, and ventilation. There were six to ten of these, increasing in depth to 30 m, and a plank road advanced westwards to connect them to the wharf. Later, the GMA extended its auxiliary mines at Old Lingan and Old Bridgeport by the same procedure. Some of the local entrepreneurs who began adits after 1858 engaged in the same process, since they were unable to afford steam-engines. We may cite as examples the Union and Gowrie mines already mentioned. Stage 2 mining was of major importance on the North Side between approximately 1790 and 1830, and on the South Side between 1835 and 1865. Even as late as 1895, however, an adit opened on the Indian Cove seam (No. 16 on Figure 1) employed stage 2 methods.

Regarding transport, the Sydney field closely parallels the model. Short wagonways connected the Lingan and Bridgeport mines to the sheltered harbour of Bridgeport Basin (Figure 5), while the Gowrie and Blockhouse companies both constructed wharfs at Port Morien and laid down wagonways to them as their workings advanced inland. Major population growth occurred at Sydney Mines and Port Morien (over 500 workers by 1865), Lingan (200 workers), and New Campbellton (100 workers). At the latter settlement, an adit worked a small outlier of the coalfield to the west of the Great Bras d'Or, not shown on Figure 1.

STAGE 3: DEEPER SINGLE-SEAM MINES

General: During stage 3, stationary steam-engines are harnessed to the task of draining deeper reserves of coal. Newcomen engines were in use from at least 1720 in British mines, but the more efficient Boulton and Watt rotative engines were not employed until around 1790. With enhanced drainage capabilities, workings now proceed rapidly by one of two methods: (1) deep shafts sunk further to the dip, or (2) slopes (drifts, or deeps) driven into the crop, with workings proceeding down-

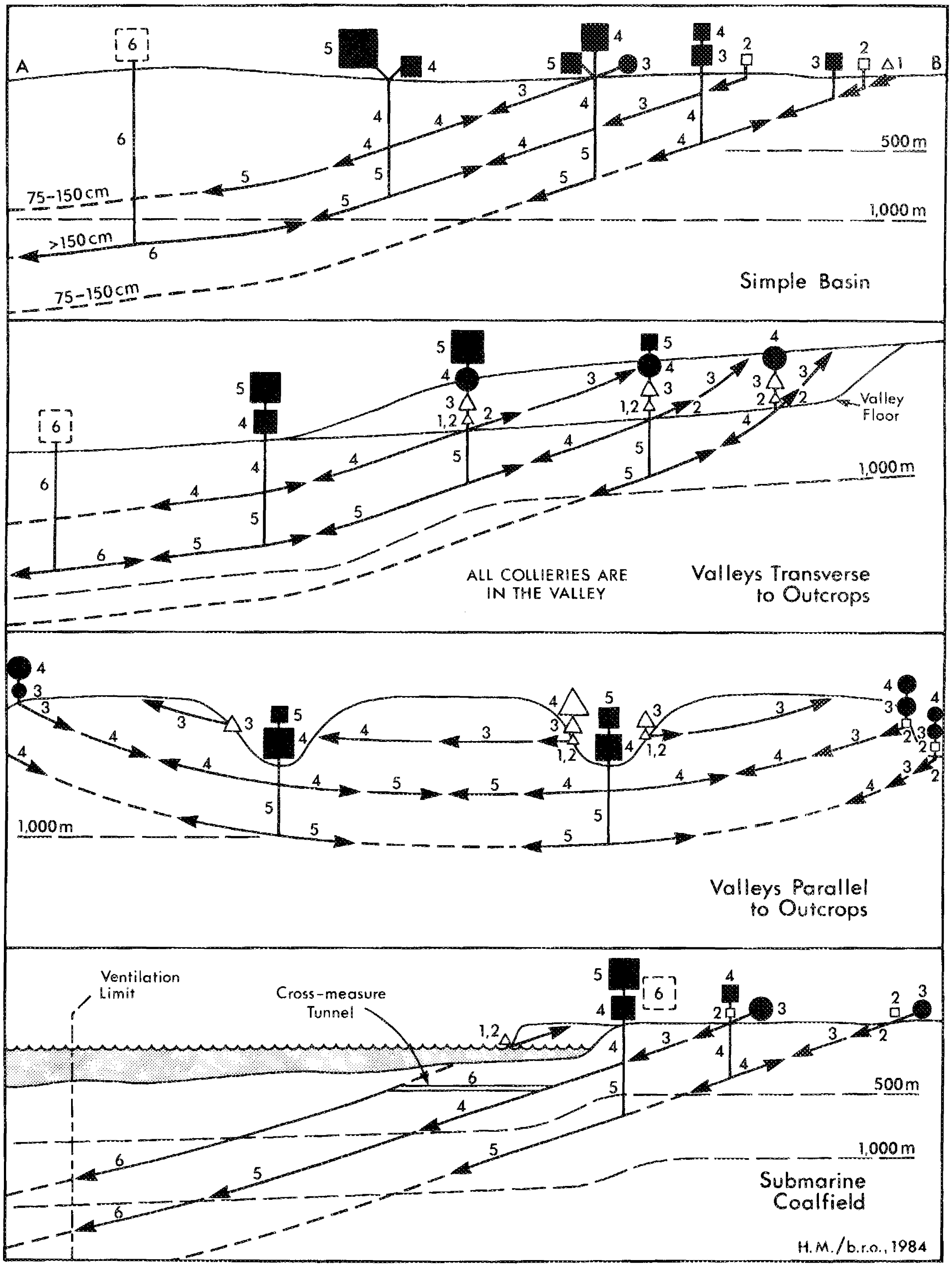

Figure 4
Cross-sections illustrating the coal exploitation sequence for different types of coalfield. Symbols for mine-types are as shown in Figure 2 and are proportional to output.

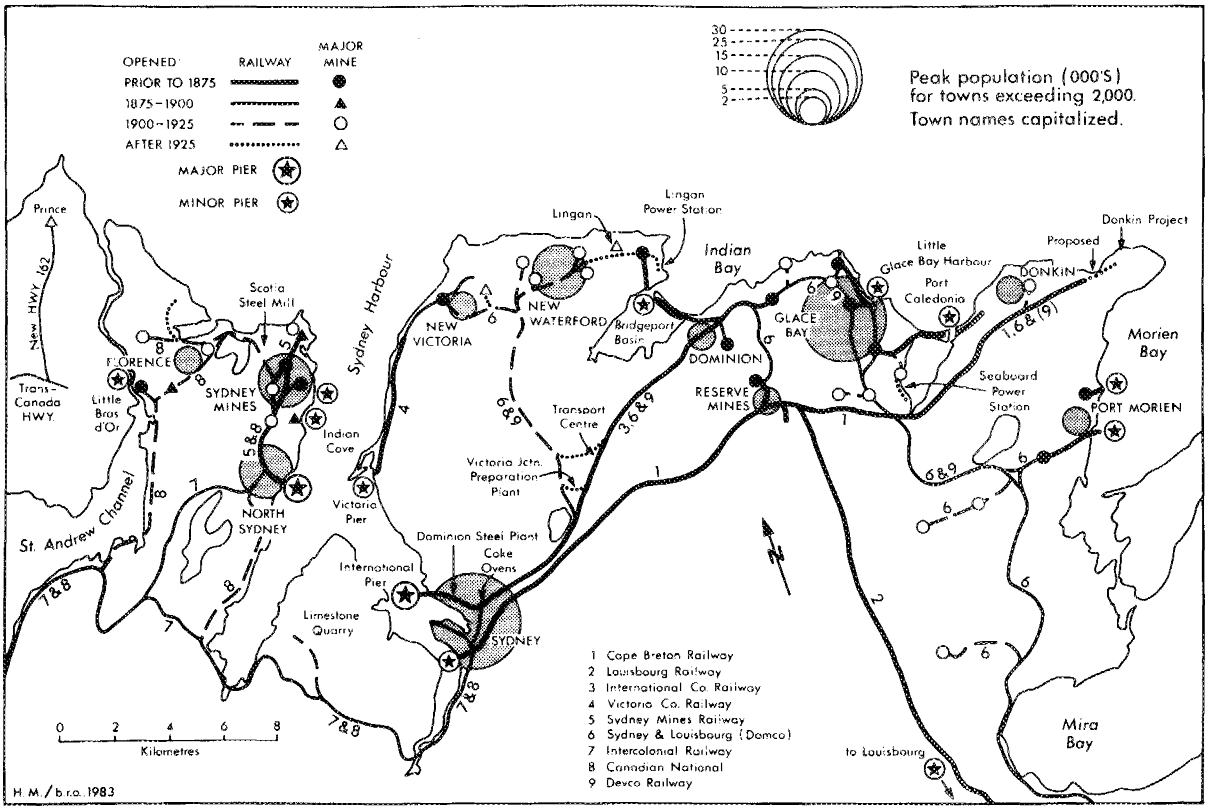

Figure 5
Transport facilities and urban development on the Sydney coalfield, related to the location of major mines

dip. Both types of mine are shown on Figure 2. They are much larger than their stage 2 predecessors, since steam engines are costly to purchase and run, so that generally only a consortium or company can afford them, and a large coal output is necessary to produce a return on the investment. Larger mines now produce 150,000 tonnes per year and employ up to 500 men. They are spaced further apart and have longer lives, since shaft-sinking or slope-driving to the new depths is extremely costly, and the workings of each mine are therefore extended as far as practicable (to an overburden of 300 m and / or a distance of about 3,000 m from the bankhead). The extent of underground workings is limited by ventilation technology and by the lack of man-transport underground, while production is limited by hand-cutting and loading at the face, the use of ponies for underground haulage, and by the slow rate of coal winding provided by steam engines.

Figure 4 shows how underground workings are related to mine size and spacing in this stage. On a simple basin, the cross-section A – B shows new shafts to the dip of the seam outcrops, with the largest production being from the shaft on the thickest seam. A new slope is shown on the seam furthest from market, on the left. All three mines exploit only the top commercial seam in their holding and work down-dip until they either exhaust their holding reserves or reach the critical overburden limit of 300 m. In the case of valleys transverse to the outcrops (for example, the South Wales coalfield), nearly all coal in stage 3 can still be won to the rise of the minesite, by extending adits well under the surrounding hills. This is true also for the 'valleys parallel' case (e.g. Appalachia, or the southern Ruhr), though slopes are shown at the edges of the basin, where the seams dip rather than rise from their valley-side exposures. On a coastal field, resources are exploited in similar fashion to the simple basin, since only landward reserves are mined in stage 3.

As Figure 3 suggests, surface transport is revolutionized during this stage by steam railways, which supplant canals and wagonways. Inland reserves may now be fully exploited, and no great advantage accrues to coastal or canal-side mines. The line of mines along a crop, or within a valley, is laced together by railways taking coal to large new shipping facilities or to nascent iron and steel industries on the coalfield itself. Individual mines may now support as many as 2,000 people, and with new employment in transport, metallurgy, and services there is rapid population growth in all but the oldest districts of the coalfield.

The Sydney field: The third stage of mining was predominant on the North Side from 1830 to 1880 and on the South Side from 1865 to about 1900. When the GMA acquired its monopoly in 1826, its new English manager, Richard Brown, imported steam-engines to enlarge and deepen Sydney Mines (No. 2 on Figure 1). The first deep shaft (the 61-m Fly Pit) was opened in 1830, immediately doubling production. It was complemented by the 98-m Jacob Pit, which boosted production to 79,000 tonnes by 1852. Finally, the 122-m Queen shaft (6), opened in 1854, exploited virtually all remaining landward reserves of the Sydney Main (i.e. Harbour) seam in the period to 1876. The vastly increased production at Sydney Mines led to the coalfield's first steam railway, from the Jacob Pit to a new and more sheltered pier at North Sydney (Figure 5, No. 5). And, in line with the model, the town of Sydney Mines coalesced into a sizeable community by 1881, with about 600 mine employees and a population of 2,340. The mines and railways required their own foundries and forges, so that a small metalworking industry developed.

The GMA did not employ steam-engines in its South Side mines until around 1860, when the Lingan adit was converted to a slope. The workings of individual entrepreneurs in the Glace Bay and Port Morien areas were modernized and enlarged by steam-engines when those entrepreneurs sold out to well-financed non-local companies. For example, Mr Archibald's lease area was sold to the Little Glace Bay Mining Co (financed in Halifax and Boston); it abandoned the adit workings and sank the 71-m Sterling shaft in 1874 (7 on Figure 1), thus employing steam drainage to access deeper reserves of the Harbour seam. It also converted the Hub mine (10) from cliffside adits to shafts and then connected both its collieries by rail to an expensive artificial harbour at the mouth of Renwick Brook (see Figure 5).

As another example of the new scale of investment, the Union Mines of Messrs Cadougan and McLeod (8) were taken over by the International Co (financed in New York) in 1863. It sank a shallow shaft, but later converted the mine to a more efficient slope, capable of working an extensive landward area of the Harbour seam. The company went on to acquire the neighbouring Bridgeport lease from the GMA and reopened the Old Bridgeport mine. With no semblance of sheltered coast on its properties, it connected both mines by railway to its own piers at Sydney (Figure 5), thus initiating the link that would draw that town into a close symbiotic association with the coalfield.

The interior of the Bridgeport basin was opened up by a second railway to Sydney in 1871, connecting to slope mines on the Emery and Phalen seams. The larger of these was the Reserve Company's mine (13), which gave rise to the community of Reserve Mines. Rapid population growth also occurred around the Caledonia mine (11), whose colliery village coalesced with Glace Bay (the joint population rose from about 1,000 in 1865 to 6,945 in 1901). The heady boom rapidly turned sour on some coal towns, however; Port Morien suffered economic and population decline when the Blockhouse mine (1) closed in 1888 due to exhaustion of its small landward reserves, followed a decade later by the Gowrie mine (9). Its population fell from 2,117 in 1881 to 1,453 in 1901. Mine closures also occurred early at Lingan and New Victoria, in both cases due to the small area of landward reserves. Figure 6 illustrates rapid rises in both production and number of mines during early stage 3, followed by the concentration of production in larger mines during the remainder of the stage.

STAGE 4: MULTI-SEAM MINES (EXPOSED), SINGLE-SEAM MINES (CONCEALED)

General: Single-seam mines opened during stage 3 rapidly deplete the top seam within their holdings and are forced to close or to access a deeper seam. Owners working the lowest seam, of course, lack the second option, while others may prefer to close rather than incur large expenditures to access a marginal lower seam. The lower seams are reached by deepening an existing

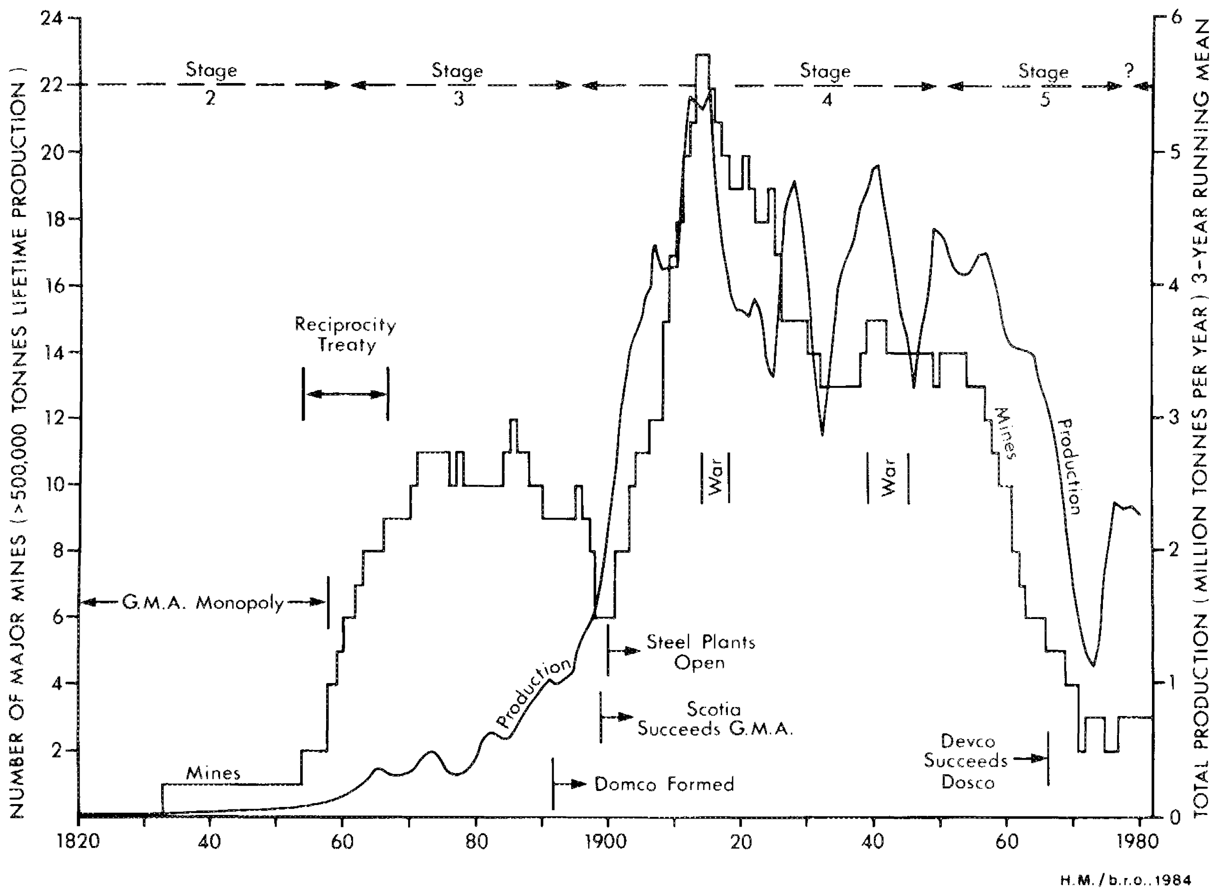

Figure 6
Number of major mines and annual coal production on the Sydney coalfield, 1820–1982

shaft, by sinking a shaft at the bankhead of a slope mine (both illustrated in Figure 4), or less commonly by driving a cross-measure tunnel from a lower part of the upper-seam workings. In coalfields indented by valleys, an analogous stage begins when owners deplete all gravity-drained coal and must switch to slope mines working down-dip or shallow shaft mines accessing the top seam below the valley floor (Figure 4).

As an alternative to multi-seam mines on the exposed field, deep shafts may be sunk to upper seams on the concealed coalfield. Prior to this century, however, such ventures were extremely risky, since the extent of the concealed field could not be accurately gauged. On a coastal coalfield, the problem of accessing submarine reserves is analogous to, and indeed more extreme than, the situation on concealed fields. During stage 4, however, mines working close to shore may gradually extend their workings under the sea. Later, new mines are strategically located on headlands for the specific purpose of submarine mining (see Figure 4).

During stage 4, face workings proceed under overburdens of up to 500 m and as far as 5,000 m from the bankhead. Due to very large shaft-sinking costs (double-shafts must now be employed for ventilation coursing and emergency access) new mines are spaced further apart, and each works a larger block. Older mines are frequently amalgamated to facilitate efficient ventilation and to reap economies of scale. Mine output must be much higher to recoup investment and is boosted by technological advances in cutting, loading, haulage, and winding. An expensive shift to longwall mining is necessitated once face workings exceed depths of 300 m, since room-and-pillar mining is both wasteful and dangerous at these depths.

Though larger companies are forced to invest heavily in this stage to reach deep reserves, small companies may scavenge along the crops of thinner and less attractive seams, often reopening portions of stage 2 mines. This phenomenon of scavenging was identified by Wilson and is characterized by small, ephemeral mines, opening and closing in response to market prices.

Coal production expands to peak levels in stage 4. Larger coalfields mature industrially, with an expansion of iron and steel industries and the introduction of textiles and clothing manufacturing to take advantage of a large pool of female labour. On a small field, one major town may dominate these activities and act as a service centre (Figure 3). Colliery villages on the upper seams fall into decline as their mines close. Their miners migrate to new jobs on the concealed field, or commute by bus to jobs in nearby towns, or remain unemployed.

The Sydney field: Stage 4 mining was important on the North Side between 1880 and 1950 and on the South Side between 1900 and 1950. On the Northside the GMA was barely equipped for the massive infusions of capital required for deep mining. When landward reserves of the Harbour seam were exhausted, it opened the Princess mine in 1877 (14 on Figure 1) specifically to mine undersea coal. It attempted an even deeper shaft (the 226-m Jubilee, 30) to access landward seams below the Harbour, but the project came to fruition only when the GMA sold out in 1900 to the Pictou-based Nova Scotia Steel and Coal Co ('Scotia'). Scotia also had the means to open up previously neglected areas to the west by slope mines, and the larger of these (the Florence, 19) was soon mining offshore. On the South Side, eight companies amalgamated in 1893 to form the Dominion Coal Co (or 'Domco'). In 1900 both Domco and Scotia created local markets for their coal by financing steel plants[15] at Sydney and Sydney Mines respectively (see Figure 5). With new mines and new markets, production climbed rapidly to a peak in 1913, thereafter oscillating around a plateau level of about four million tonnes per year (Figure 6).

Domco was repeatedly forced to reorganize its operations to account for the depletion of landward reserves. In the Bridgeport basin, for example, the landlocked Reserve mine (13) worked all its Phalen coal and was then forced to sink a shaft to the lower Emery seam. Finally a rock slope was tunnelled to the even lower and thinner Gardiner. Coastal mines, in contrast, simply extended their Phalen workings undersea, a safe operation provided at least 60 m of rock cover was maintained. Dominion No. 1 (3 on Figure 1) was eccentric to its offshore reserves, however, so that its Phalen workings were continued by the strategically sited 1-B (33) after 1924. In a rather desperate bid to maintain production at No. 1, a rock slope was driven down to the Gardiner, but the seam proved to be too thin, and the mine closed in 1926. The exploitation sequence underground had its impact on the surface, as first Dominion and then Reserve Mines suffered economic decline. Glace Bay, in contrast, grew steadily due to the favourable position of its mines, which extended their workings well offshore. Its population grew from 6,945 in 1901 to 25,586 in 1951.

During stage 4 the New Waterford area was rapidly opened up through a series of slope mines on the Phalen and Harbour seams. The area had been neglected earlier due to lack of both capital and markets, but progressed quickly to offshore mining, owing to the proximity of the crops to the shore. To rationalize submarine mining, all production was later assigned to just one large mine on each seam (23 and 26 in Figure 1). The town of New Waterford, which housed the work-force for these closely spaced mines, grew from nothing in 1901 to 10,423 in 1951 (see Figure 5).

Not all mines on the lowest seams closed at the beginning of stage 4. Smaller companies working south and west of Sydney Mines (notably the Toronto mine, 4, and the Greener mine, 16) were able to purchase sub-leases from Scotia, which had no interest in sinking expensive shafts to relatively thin seams. In the same area and along even less attractive seam outcrops, a series of scavenger pits worked very much in the fashion described by Wilson for the New South Wales fields. As examples, the Black Diamond and Last Chance pits operated for only three and two years respectively in the 1930s, and each produced under 10,000 tonnes. Scavenger mines existed also on the Tracy seam in the 1950s, and a bootleg scavenger quarry was operating on the Emery seam near Glace Bay as recently as 1982.

STAGE 5: SURFACE CLEARANCE (EXPOSED), MULTI-SEAM MINES (CONCEALED)

General: On vintage coalfields this stage, still proceeding, sees the virtual abandonment of the exposed field and the mining of very deep reserves on the concealed field. A few collieries may survive on the boundary of the exposed field, accessing reserves up to 1,000 m in depth and offsetting decreased coal quality through increased productivity. On the concealed or submarine field, mines sunk earlier are deepened (and concurrently expanded to reap economies of scale), while new mines tap deeper or more remote reserves. They often work several seams simultaneously. Employment per mine rises less rapidly than production, due to productivity increases achieved by fully automated longwall faces. Nevertheless, a typical mine now employs 1,000 to 1,500 and acts as the economic base for a town of 5,000 people.

Though underground mining ceases on the exposed field, several activities begin or expand to glean all remaining coal from the surface – hence the term 'surface clearance.' Most important is strip-mining, which began in a small way in the 1920s (during stage 4), but became widely applicable only after 1945.[16] On newly developed exposed fields, stripping is employed in preference to underground mining wherever possible, but is particularly attractive where the seams are horizontal or dip only gently. In such cases, coal from several seams may be extracted down to 300 m or more. A second 'clearance' activity is the recovery of marketable coal from old waste tips. This is sometimes combined with stripping, and both activities are increasingly concluded by environmental rehabilitation.[17]

Regarding the settlement pattern (Figure 3), most communities on the exposed field decline, particularly those losing both mines and the heavy industry associated with them (i.e. iron and steel). The decline may be cushioned or even reversed by economic incentives designed to attract alternate employment to selected growth nodes, and certain communities may grow as dormitory suburbs. The rail network is partially dismantled, most coal now being shipped by key lines to large thermal-electric generating stations. Where possible, as in coastal areas, these stations are located adjacent to the mines.

The Sydney field: Stage 5 mining is prevalent on the Sydney field from 1950 to the present. The last large mine working landward coal was the Reserve (13), which closed in 1959, though the small Four Star mine (35) worked the largely overlooked Tracy seam until 1969. The number of major mines on the field dropped from fourteen to two in just twelve years, but output per mine tended to increase (Figure 6).

Strip-mining was experimented with in the 1920s north of Florence,[18] but was not undertaken extensively until 1974. Since then, areas at Alder Point and on Boularderie Island have been stripped (see Figure 1), and extensive stretches on the crops of the Tracy, Mullins, and Emery seams have been identified for future stripping.[19] The tendency, clearly, is for opencast work to recover neglected reserves in remote areas or on formerly unattractive seams. At the same time, coal reclamation is sorting marketable coal from the coalfield's two largest waste tips, at Sydney Mines and The Summit (New Waterford). Owing to increased coal prices and more thorough geologic investigation, the possibility of new small slope mines on interior sections of the Tracy and Mullins seams has been mooted,[20] and this may be viewed as part of an overall gleaning process.

The early part of stage 5 saw a shift to the mining of two seams in offshore blocks. At New Waterford the Dominion No. 16 slope worked offshore reserves of the Phalen, while the neighbouring No. 12 slope worked overlying Harbour reserves in the same block (23 and 26 on Figure 1). Two of the largest and longest-lived collieries were multi-seam shafts mining both the Phalen and Harbour offshore (17 and 33 on Figure 1).

Most mines working offshore closed during the 1960s and early 1970s. They had reached the limits of their capital equipment in terms of ventilation distances, length of haulage lines, and depth of overburden. Two new submarine mines were opened in the 1970s, however, to tap offshore coal blocks prudently reserved earlier. The Lingan (36) and Prince (37) work only one seam each, but Devco[21] is currently developing a slope to mine underlying Phalen reserves in the Lingan block (38). The development of a 'twin' Lingan mine was pushed ahead by the need to maintain production and employment following the unforeseen closure of No. 26 colliery by fire in 1984.

As already suggested, coastal communities where offshore mining was not pursued declined earliest (e.g. Port Morien, Lingan, Victoria, Donkin), followed by inland communities with limited reserves (e.g. Birch Grove), and then inland communities with large reserves (e.g. Reserve Mines). During stage 5, large coastal towns dependent on offshore mining also suffered: New Waterford's population declined from 10,423 in 1951 to 8,808 in 1981, while Glace Bay declined from 25,586 to 21,466. The new mines draw their workers from existing communities – miners commute to the Prince from Sydney Mines and Florence, for example – but total colliery employment is only a quarter of the 1950 level. Attempts to attract new industry have been made, as testified by the presence of the Glace Bay Heavy Water Plant, but the region is poorly located with respect to markets, and mining's legacy of poor labour relations and an unattractive physical environment is not conducive to economic diversification. The heavy water plant has now closed, and the Sydney Steel mill remains threatened with closure.

Regarding transportation, Devco retained lines linking its two largest producers (Lingan and No. 26) to the Sydney pier. At the strategic Victoria Junction (Figure 5), a new coal preparation plant washes and grades coal, and a transport centre for the railway is under construction. Two thermal power stations now take over half of Devco's production: the Seaboard plant at Glace Bay (90 Mw) was developed in 1930 and took coal from the adjacent No. 24 and Caledonia mines, while the new 600-Mw Lingan station takes most of the Lingan colliery's output. The Prince mine has yet to be connected to the Devco railway, but a new limited-access highway serves it for both coal shipments and worker access.

STAGE 6: SUPER-MINES

Recently, a new type of coalmine has come about, due to scale economies related to a new round of automation both above and below ground. These super-mines may be defined as having a production capacity of at least two million tonnes per annum. The Lingan mine on the Sydney field virtually falls into this category (its peak production was 1.78 million tonnes in 1978) and in layout and production incorporates features typical of deep super-mines.[22] Among these are a preference for drifts rather than shafts (allowing coal to be raised rapidly by continuous conveyor), the working of a single thick seam, an extensive reserve block to be worked to depths of up to 1500 m, and productivity levels exceeding 1,500 tonnes per man-year. Individual mines are unlikely to exceed three million tonnes in the near future, due to prudence related to mine safety and investment risk. However, the linking of several existing mines to a single output drift is an increasing trend and when applied to new fields may result in enormous outputs. The world's largest deep-mine complex, currently opening a 15-by-15-km reserve at Selby in Britain, will see the combined output of five 2-million tonne satellite mines output at a single drift.[23] On Figure 2, a super-drift of this type is suggested, with satellite shafts used for ventilation, men, and materials. While each new mine may employ 1,000 to 1,500 workers, the current preference is for these to commute from existing colliery towns and / or for new housing to be integrated in several existing rural communities (see Figure 3).

On a submarine field, stage 6 necessitates the development of reserves in seams outcropping offshore. Where these seams overlie areas already worked, they may be reached from existing mines by cross-measure tunnels (a stratagem already employed on the Sydney field at the No. 26 and New Aberdeen collieries). New super-drifts, however, may be developed specifically to exploit offshore seams: on the Sydney field the Donkin project, currently under construction (39 on Figure 1), is envisaged as producing up to two million tonnes per annum from the Harbour seam and a further one million from the Hub seam.[24] Should this mine be successfuly developed (it may be reduced in scale due to excessive capital costs), its work-force will commute almost entirely from Glace Bay.

Summary and Conclusions

This paper has set out a generalized sequence of coalfield exploitation and development and has illustrated key aspects of the development process by reference to the Sydney coalfield. The generalized sequence is a model in two parts; the first part graphically portrays the typical or natural sequence of coal exploitation, which primarily takes place underground, while the second part illustrates the sequence of transport and settlement development, which is the surface expression of the process. For geographers, regional planners, and policy-makers, surface developments are undoubtedly of major concern, but these developments are intelligible only when related to the underground exploitation sequence.

The problem of accessing more and more remote reserves (remote in terms of cost) is a three-dimensional problem related to seam geology and the surface configuration of the land. There is a natural sequence or order of preference by which coal reserves are exploited, and the six stages of the model essentially spell out this sequence. The surface expression of the process may differ markedly for different types of fields – coastal fields or those with deeply indented topography will develop much differently to a plateau or plain, as was suggested by Figure 4. However, providing one is armed with a knowledge of local seam geology, the model provides a useful explanatory framework, within which the details of development on any particular field may be fitted.

If one allows for certain lags in the development sequence due to the vagaries of company planning and financial resources, then virtually all developments on the Sydney field may be related to the model and become more intelligible as a consequence. This is important since, as suggested earlier, this field is by no means an easy test case. The model is more directly applicable to large and homogeneous inland fields such as the Yorkshire-Derbyshire-Nottinghamshire or the Ruhr. That it may be usefully employed in relation to the small, fragmented, and coastal Sydney field demonstrates its versatility and range of applicability.

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Notes and References

1 The relation between mining and regional economics is succinctly summarized in Derek Spooner *Mining and Regional Development* (New York: Oxford University Press 1981). Environmental and social problems of mine development have been clearly illustrated by the furore over the Vale of Belvoir proposals in the United Kingdom (see J. Herington and W. Hamby 'The Price of Coal in Belvoir') *Geographical Magazine* 50 (1978) 307–14.

2 Homer Aschmann 'The natural history of a mine' *Economic Geography* 46 (1970) 172–89

3 Hugh Millward 'Mine locations and the sequence of coal exploitation on the Sydney Coalfield, 1790 to 1980' in K. Donovan ed *Cape Breton: Essays in Honour of the Island's Bicentennial* (Sydney: College of Cape Breton Press 1985). This paper identifies 73 separate mines and examines their locations. Complete production data for these mines have been tabulated and are available on request.

4 While not an exhaustive list, the following were particularly useful: B. Duckham *A History of the Scottish Coal Industry, Vol. 1: 1700–1815* (Newton Abbot, Devon: David and Charles 1971); Alan Griffin *Mining in the East Midlands, 1550–1947* (London: Frank Cass and Co 1970); M. Wilson 'Changing patterns of pit locations on the New South Wales coalfields' *Annals, Association of American Geographers* 58 (1968) 78–90; J. Langton *Geographical Change and Industrial Revolution: Coalmining in South West Lancashire 1590–1799* (Cambridge: Cambridge University Press 1979); N. Pounds *The Ruhr: A Study in Historical and Economic Geography* (New York: Greenwood Press 1968).

5 Early mining technology is thoroughly treated by the above references. Modern mining techniques are described in N. Berkowitz *An Introduction to Coal Technology* (New York: Academic Press 1979); S. Cassidy *Elements of Practical Coal Mining* (New York: American Institute of Mining, Metallurgical and Petroleum Engineers, Inc 1973); and G. Fettweis *World Coal Resources: Methods of Assessment and Results* (New York: Elsevier 1979).

6 Wilson 'Changing patterns.' Other models and theories have been proposed, but they are generally only partial. Thus A. Hay ('A simple location theory for mining activity' *Geography* 61 [1976] 65–76) provides a useful model of economic equilibrium but does not explicitly account for historical inertia or for changing mining technologies. Langton (*Geographical Change*) provides a systems diagram portraying variables affecting the number, size, spacing, and duration of mines, but this is simply a 'scheme of enquiry.' Philip Jones (*Colliery Settlement in the South Wales Coalfield 1850–1926* [Hull: University of Hull Occasional Papers in Geography no. 14, 1969]) develops a detailed and very specific 'model of colliery settlement growth' but fails to provide a clear sequence of mine sizes and locations, since his interest is the internal morphology of colliery towns. Finally, Spooner (*Mining*) identifies three broad stages of mining-region development but fails to develop a general spatial model. The paucity of model development related to mining is noted in E. Grant 'Historical geography of mining' *Journal of Historical Geography* 5 (1979) 435–56.

7 While Wilson's analysis of two New South Wales fields demonstrates his awareness of these relationships, the historical periods he identifies are specific to each field, and he fails to generalize them or to incorporate scale changes in his model.

8 On the social and economic development of the area, see E. Forsey *Economic and Social Aspects of the Nova Scotia Coal Industry* (Montreal: McGill University Press 1926); J. Donald *The Cape Breton Coal Problem* (Ottawa: Queen's Printer 1966); D.Muise 'The making of an industrial community: Cape Breton coal towns 1867–1900' in D. MacGillivray and B. Tennyson ed *Cape Breton Historical Essays* (Sydney, NS: College of Cape Breton Press 1980).

9 A comparison of Canada's coalfields at mid-century is provided in W. Carroll (Chairman) *Report of the Royal Commission on Coal, 1946* (Ottawa: King's Printer 1947).

10 See R. Brown *The Coalfields and Coal Trade of the Island of Cape Breton* (London: Sampson Low, Marston, Low and Searle 1871); D. Frank 'The Cape Breton coal industry and the rise and fall of the British Empire Steel Corporation' *Acadiensis* 7 (1977) 3–34; F. Gray 'Fifty years of the Dominion Coal Company' *Dalhousie Review* 22 (1942–3) 461–9. For a general account of the field's evolution, see H. Millward 'The development, decline, and revival of mining on the Sydney coalfield' *Canadian Geographer* 28 (1984) 180–5.

11 See B. Haites 'Some geological aspects of the Sydney coalfield with reference to their influence on mining operations' *Canadian Mining and Metallurgical Bulletin* 44 (1951) 329–39; P. Hacquebard 'A geological appraisal of the coal resources of Nova Scotia' *CIM Bulletin* 72 no. 802 (1979) 76–87; and Nova Scotia Department of Mines and Energy *Energy: A Plan for Nova Scotia: Summary Report* (Halifax: 1980).

12 This is in line with typical seam geology and at variance with Wilson's statement that lower seams of a series have higher quality. See I. Williamson *Coal Mining Geology* (London: Oxford University Press 1967) chap. 13.
13 Langton *Geographical Change* 106
14 Brown *Coalfields* 46–7, 57–9, 63
15 See R. Hindson 'Steel in Cape Breton' *CIM Bulletin* 69 no. 767 (1976) 122–7.
16 See Fettweis *World Coal Resources* section 3.7.
17 See C. Down and J. Stocks *Environmental Impact of Mining* (London: Applied Science Publishers 1977); and I. Marshall *Mining, Land Use and the Environment; 2: A Review of Mine Reclamation Activities in Canada* (Ottawa: Environment Canada, Lands Directorate 1983).
18 J. Reid 'Strip-mining in Cape Breton' *CIM Bulletin* 67 no. 752 (1974) 75–9
19 D. MacNeil 'Coal exploration in the Sydney coalfield in 1982' *Mines and Mineral Branch Report of Activities, 1982* (Halifax: Nova Scotia Department of Mines and Energy 1983) 1–3
20 Nova Scotia Mines and Energy *Energy* 32–44
21 Devco (Cape Breton Development Corporation) is the federal crown corporation that took over from Dosco in 1967.
22 J. Marsh et al 'Development and production at the Lingan Mine, Cape Breton Island' *Canadian Mining and Metallurgical Bulletin* 66 no. 733 (1973) 62–9
23 R. Dunn 'Underground development of the Selby coalfield' *CIM Bulletin* 69 no. 765 (1976) 51–9
24 Nova Scotia Mines and Energy *Energy* 185

Observations
DU NOUVEAU AU *GÉOGRAPHE CANADIEN*
Rédacteur en chef

Le Géographe canadien publiera dorénavant des 'Observations' qui combleront les espaces blanches, parfois plus d'une demie page, qui suivent la fin des communications. D'une part, une Observation pourrait être présentée dans deux colonnes. Celle de gauche servirait pour une présentation visuelle, soit une carte, une photo, un graphique, ou autre, ou même une citation. La colonne de droite contiendrait un texte approprié, jusqu'à 300 mots. D'autre part, une Observation pourrait consister d'un bref rapport, limité à 500 mots, sur un projet de recherche, ou l'auteur pourrait saisir l'occasion pour provoquer une dialectique. L'objectif pourrait être: d'interpréter les directions pris par la discipline de soulever des questions, de présenter des problèmes, de formuler des hypothèses, ou d'initier une discussion.

Le premier exemple d'une Observation se trouve sur la page 273 de cet édition. On anticipe en présenter de deux à quatre dans chaque édition du *Géographe*.

Veillez soumettre vas 'Observations' au rédacteur, en suivant les 'Avis aux Auteurs,' qui se trouvent dans l'édition du printemps 1985 (Vol 29, no 1), sur les pages 94 à 96.