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HISTORICAL RESEARCH REPORT

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1985

Studies of the Scottish oil shale industry. Seaton A, ed Vol.1 History of the industry, working conditions, and mineralogy of Scottish and Green River formation shales Final report on US Department of Energy Project DE-ACO2 – 82ER60036

Louw SJ, Addison J

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STUDIES OF THE SCOTTISH OIL SHALE INDUSTRY

Editor: Dr. A. Seaton

VOLUME 1

HISTORY AND MINERALOGY

S.J. Louw and J. Addison

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STUDIES OF THE SCOTTISH OIL SHALE INDUSTRY

FINAL REPORT TO THE U.S. DEPARTMENT OF ENERGY
ON RESEARCH PROJECT NO. DE-AC02-82ER60036

Editor: Dr A. Seaton

VOLUME 1

HISTORY OF THE INDUSTRY, WORKING CONDITIONS, AND MINERALOGY OF SCOTTISH AND GREEN RIVER FORMATION SHALES.

by
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PREFACE

These three volumes report research carried out, under contract to the United States Department of Energy, into the effects on the health of its workforce of the now-defunct Scottish oil shale industry. This industry had a life span of some 112 years from its foundation in 1850, when James 'paraffin' Young constructed a facility to retort and refine cannel coal near Bathgate, West Lothian. At its peak, in 1913, the industry employed 10,000 people though economic factors forced its subsequent gradual decline and the final blow was struck when the differential excise duty was withdrawn in 1962.

The first volume recounts in brief the technological history of the industry's mines and retorts. This is based on a survey of available documents which, together with first-hand accounts from interviews with surviving shale workers, have also been used to make an assessment of dust conditions and of safety precautions in the industry. Finally, volume one also includes a mineralogical characterisation of Scottish shales compared with those from the Green River formation in the Colorado Rockies.

Volume two reports a study of skin disease, radiological abnormalities, lung function and smoking habits of surviving ex-shale workers. The men were identified from a Provident Fund run by their final employer, Scottish Oils Ltd. The same Fund records were used to identify deceased ex-shale workers, whose patterns of mortality have been investigated. This mortality study forms volume three.

The work has involved many people, both on the staff of the Institute and elsewhere. Especial mention should be made of Dr Victor Heslop and the staff of B.P. (Oil) Ltd, Miss Jane Clark of Bangour Hospital, West Lothian and the late Mr George Webster who supervised the Provident Fund until his retiral from BP(Oil) Ltd and without whom this study would not have been possible. These volumes are dedicated to his memory.

CHAPTER 1

HISTORY OF MINING TECHNOLOGY

1.1 Geographical distribution of Mines

The first geological description of the shale mining area in Scotland was that of Sir Archibald Geikie on behalf of the Geological Survey in 1857. The subsequent expansion of the shale industry necessitated a re-survey which was performed by Mr H.M. Cadell in 1887, for the Geological Survey. The results of these surveys were comprehensively discussed in a publication of the Geological Survey Office, 1927. The most recent official report dealing with the present resources, as well as a description of former workings, was published in 1978, by the Institute of Geological Sciences (IGS)[1], and much of the following information has been obtained from this source.

Briefly, the oil-shales of the Lothians consist of an outcrop "in the area which extends from the Firth of Forth, between Blackness and South Queensferry, south through the former major producing areas of Philpstoun, Broxburn, Pumpherston and West Calder to Tarbrax". This area comprises about 50 square miles. Small areas of oil-shale also existed at Straiton, Midlothian and near Burntisland in Fife.

1.2 Stratigraphy

The oil shales are very fine grained, laminated, fissile, argillaceous rocks, generally dark grey or dark brown in colour; they are sectile, and when cut or ground produce a rich ochreous coloured powder. They occur within a series of mudstones, sandstones, marls, marine and fresh-water limestones, together with a few thin coal seams, known as the Upper and Lower Oil-shale Groups. These rocks are the local (East of Scotland) development of the Carboniferous Limestone Series (= Dinantian, part of the Lower Carboniferous).

About 15 separate oil-bearing shale seams have been recognised, none more than a few yards thick in their maximum development, and together comprising no more than about 140 feet in total out of a whole sequence of about 3000 feet for both the Upper and Lower Oil-shale Groups.

The most important economic seams were the Broxburn, Fells, Camps,Dunnet (including Under Dunnet and Upper Dunnet) and Champfleurie shales in the Upper Group, and the Pumpherston Shales in the Lower Group. Most of the seams occur and were worked as single layers, but the Broxburn Shale and Pumpherston Shale are in fact the names for closely spaced groups of seams which were usually mined together.

The regional geological structure of the area dips to the west, so that the seams outcropping in the west are generally those of the younger Upper Oil-shale Group, while those of the older Lower Oil-shale Group are found in the east or at some depth in the west. This simple structure has been complicated by a series of folds with roughly north-south axes. The folds have subsequently been subjected to complex, but generally east-west, faulting which has produced an extremely complicated outcrop pattern and structure and has probably been responsible for the somewhat piecemeal exploitation of the resources. Intrusion of later Carboniferous igneous dykes and sills has also led to local induration of the oil-shales and a reduction in the amount of usable shale.

The whole of the area is covered by more recent boulder clays and gravels so that surface exposure of the shales occurs at no more than a half-dozen localities. The thickness of the overlying deposits varies from between a few yards to 20 yards.

1.3 The shale mines

1.3.1 Numbers of mines

Although the total number of shale mines that were worked throughout the life of the industry probably exceeded 100, it is recorded that during the decade 1910 - 1920 the average number of mines in operation at any one time was 45.[2] It should be noted that the average lifespan of mines at that time was 5 years. In 1926 there were only 6 shale-oil companies (subsidiaries of Scottish Oils Ltd.) left, and these were working 13 shale mines in that year[3]. By 1938 there were only 12 mines in operation, which were conveying their raw shale to five retort-works[4]. In 1950 there were also 12 pits in operation[5], in addition to which open-cast workings at two sites were being exploited[6]. A detailed map of all significant mines, together with a table of their dates of abandonment was compiled by Marine *et al*.[7]

1.3.2 Depth of mines

The marked local faulting in the strata (see section 1.2) required some mines to be sunk to substantial depths, whilst at other sites open-cast mining was feasible. Sneddon *et al*[4] reported that in 1938 some mines were 1200ft deep. According to MacLennan[5], several mines were over 400ft deep: the winding machine at Breich pit was designed to operate at a depth of 432ft, while the Burngrange and Fraser pits were 432ft and 411ft deep, respectively. The inclined mines, No.6 Philpstoun and Hermand mine, required their winders to work at distances of 750ft and 2000ft, respectively[5]. Westwood mine was 720ft deep in 1948[8].

1.3.3 Width of worked seams

The chief seams worked before 1890 were the Fells (3'6" thick) and Broxburn (4'6") seams in the south. In the north the Broxburn seam was 5'6" thick[4]. In the first two decades of this century, the average worked seam was 7ft thick (range 4-10ft), and usually relatively free from unproductive rock[9]. In 1948 the Westwood mine worked two seams, namely the Broxburn,(which was 4-6ft deep at 420ft) and the Dunnet seam (which was 9-10ft thick at 720ft).

1.4 Tons produced

The annual combined production of all the shale mines in West Lothian is reflected in Table 1.1 below.[2,4,10] Although the actual annual production figures are available, 10 yearly figures only are shown. The production of 1913, which was the peak production year during the life of the industry, is also shown. (Tons = Long tons = 2,240lbs).

Table 1.1 Tons of raw shale produced (per annum)

Year	Tons
1873	524 000
1875	423 000
1885	1 742 000
1895	2 236 000
1905	2 492 000
1913	3 280 000
1915	2 993 000
1925	2 458 000
1935	1 408 000
1945	1 393 000
1955	1 336 000
1960	669 000
1961	468 000

1.4.2 Yield per ton

The richer shales, with higher oil yields are found on top of the poorer shales. Thus, the Fells seam of the southern district was stated to have yielded 40 gallons crude oil per ton of raw shale when it was worked in 1864-1885. By 1875 the average yield of crude oil in Scotland was 30 gals per ton; by 1938 the average yield had dwindled to 20 gals per ton[4]. The yield of the Westwood retorts (the only retorting facility in operation in 1950) was typically 19.53 gals per ton of crude oil and 3.66 gal/ton of crude naphtha[11].

1.5 Workforce

1.5.1 Variations over time

The maximum number of miners employed in the Scottish shale industry was slightly more than 5,000 men in 1914. Fig. 1.1 shows the number of miners employed during most of the active life of the industry. Between 1939 and 1962 there was a downward trend, steeper during the war years and again towards the end of the 1950's.

1.5.2 Distribution of workforce in mines

In a wage dispute investigation in 1926, a breakdown (Table 1.2) of the workforce of the Scottish Shale oil industry was given in evidence.[3]

Table 1.2: Workforce in the Scottish Shale mines in 1926

Mines		No.employed
Miners		1201
Drawers		1233
Youths		60
Oncost below	Men	832
	Boys	269
Oncost above	Men	658
	Boys	62
	Total	4315

The term "miners" generally implied faceworkers. In Scottish Shale mines it was the usual practice to allocate

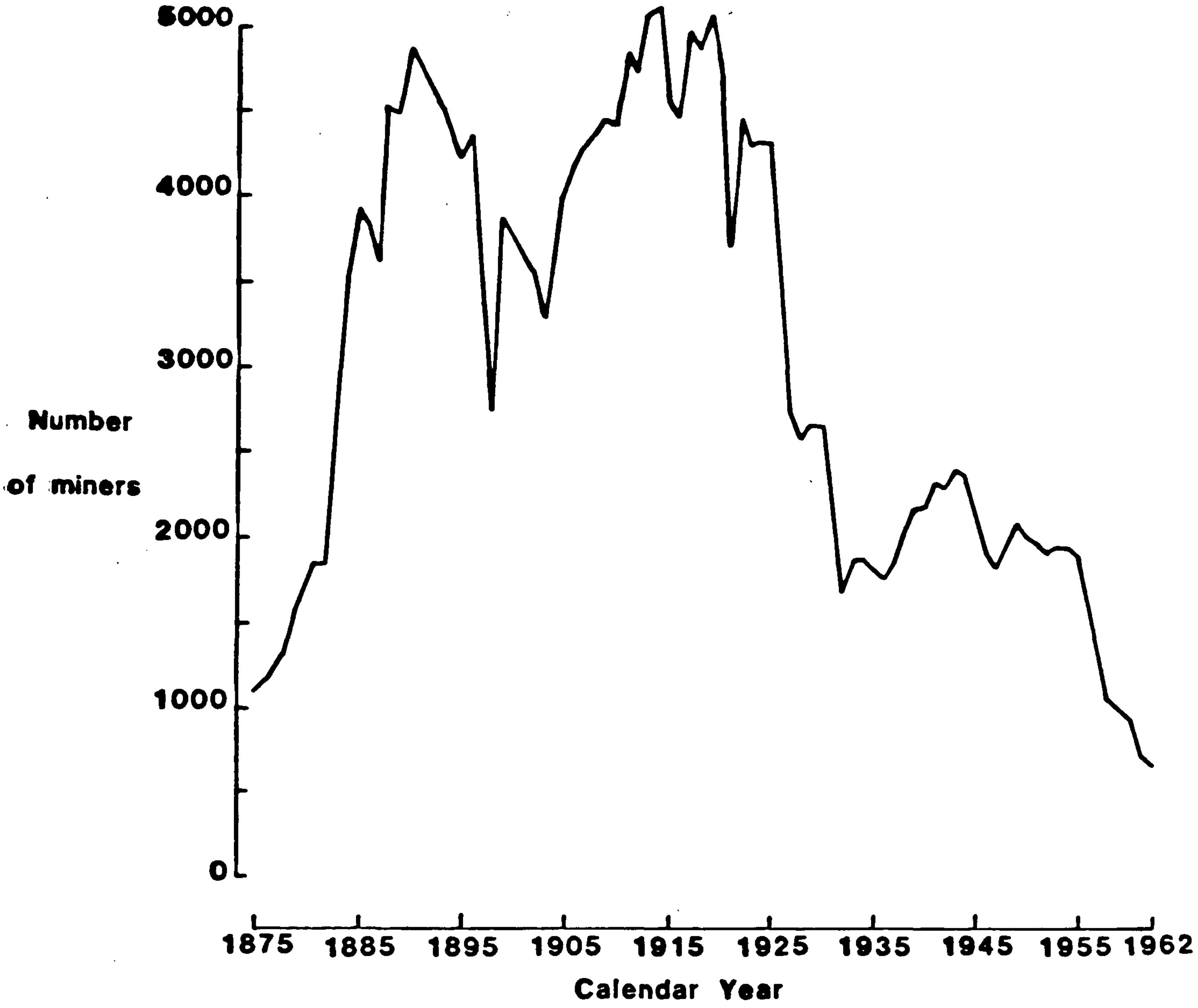


Figure 1.1 Number of miners employed in the Scottish shale industry; 1875 to 1962.
Sources: Secretary of Mines reports (for 1875 to 1938); Department of Energy, Economics and Statistics Division (for 1939 to 1962).

the driving of a level to "contractors" or "placemen", who were responsible for management of the working face. The placeman often had a "shift-face-man" to assist him and a "drawer" was employed to fill the hutches, "drawing" them to the inclined shaft. Production for such a unit of 3 men was 9 tons per shift[9].

By 1950, a "modified stoop-and-room" technique (see Section 2.2.3) had been developed, whereby the adoption of conveyor belts increased output to 12 tons per faceworker. The arrangement still required a basic 3-man team at each workplace, and a relatively large number of oncost workers was also required.
Table 1.3 sets out the jobs that were designated to each fully working "panel".

Table 1.3: Jobs at each working panel

	Man per shift
assembly of empty hutches	1
despatch of full hutches	1
loading operation	1
attendance at transfer point	1
all conveyor maintenance	1
general purposes	2
oversman and fireman	1
	8

Since each "panel" had 6 active workplaces, 18 men were "producers" together with the 8 oncost workers. The average production per man per shift was thus $7^3/_4$ tons for the whole panel. Additonal manpower was required for the distribution of explosives, supports, dismantling, fitting and reassembly of conveyor-belt units[12].

The longwall technique of mining was employed sporadically, and on a relatively small scale. Caldwell et al[13] provided a detailed description of the mode of working in two experimental workings between 1941 - 1946. At the mine in question (Breich Pit), mechanised coal-cutters were utilised and the total number of men working on the face was forty.

Opencast mining took place at Philpstoun at the turn of the century, but since only about five small sites in West Lothian were suitable for such workings the most profitable ones were soon exhausted. Owing to the labour shortage during World War II, new sites for opencast mining were considered, and two such sites were worked in the 1940's. Caldwell et al[13] described the working of one at Livingston in detail. Only 18 men were employed at this site. (see section 2.2.4).

1.6 Hazards

Compared to coal-mines, shale mines were regarded by the miners as cleaner, roomier, wetter, better ventilated, less dusty and safer.

1.6.1 Gases

Contemporary reviewers of the shale mining industry appear to be in agreement that "firedamp" (methane, CH_4) was not often found in shale mine workings. Caldwell[9], cautioned that neglect of the "ordinary precautions in regard to ventilation" could lead to the danger of explosions. Winstanley[14] stated that "very little firedamp is encountered in the workings, and the use of open lights is permissible throughout". Small quantities of firedamp tended to occur at developing ends, faults and wastes, but this was controlled by adequate ventilation. Despite these disclaimers, occasional explosions with injuries of miners were reported to H.M. Divisional Inspector of Mines from time to time. For example, between 1933 - 1937, nine persons were burned by firedamp explosions and further explosions occurred in 1947, 1950, 1952, 1954 and 1956.[15]

Caldwell in 1927 drew attention to the hazard of "choke-damp" (carbon dioxide mixed with nitrogen) which was occasionally found to accumulate in shale seams.[9] It has proved impossible to find a record of the prevalence of this hazard.

1.6.2 Dust explosions

It is generally agreed that dust explosions did not occur in Scottish shale mines. Experiments, described by Caldwell[9] and reported in Transactions of the Institution of Mining Engineers in 1910,[16] suggested that shale-dust was retardant to flame-propagation, in contrast to the action of coal-dust. In the light of these findings and with the benefit of additional years of practical experience, Sneddon et al[4] concluded in 1938 that shale dust was not inflammable.

1.6.3 Fumes

The fumes resulting from the large amount of gunpowder explosion required in shale-mining was responsible for the principal complaint elicited from ex-miners during numerous interviews by the author. Sneddon et al[4] stated that (in contrast to firedamp), "what has weighted mostly in oil-shale mines has been the speedy removal of the fumes arising from the amount of blasting necessary." These authors went on to say that when the fumes were adequately removed, dangerous gases would also have been removed.

1.6.4 Rock-falls

The hazard of falls of ground was regarded to be, by far, the greatest hazard in shale mines at working faces. Winstanley in 1938[14] reported that 379 accidents resulting in disablement lasting more than 3 days, 11 serious non-fatal accidents and 7 fatal accidents occurred during the five-year period 1933-1937;[13] at this time the underground workforce was about 1500 men.

1.6.5 Transport

Accidents resulting from derailments, breakages of gear or failure of men to leap clear of moving tubs resulted in serious accidents. During the 5 year period 1933 - 1937 there were 11 serious accidents underground, involving "run over or crushing by tubs" and 5 serious accidents due to other causes. There were no fatalities underground due to transport accidents during this period, although one fatal accident did occur on the surface.[14]

1.6.6 Explosives

Although half a million shots were fired every year, only four non-fatal and one fatal accident from blasting occurred during the 5 years 1933 - 1937.[14] Caldwell[9] offered a description of the procedural errors that might result in blasting accidents and emphasised the close control demanded by the mining managers, in addition to the statutory requirements. No doubt the scrupulous application of these safety precautions was responsible for the low accident rate in succeeding years.

CHAPTER 2

TYPES OF SHALE MINE, TECHNIQUES, EQUIPMENT

2.1 Access to seams

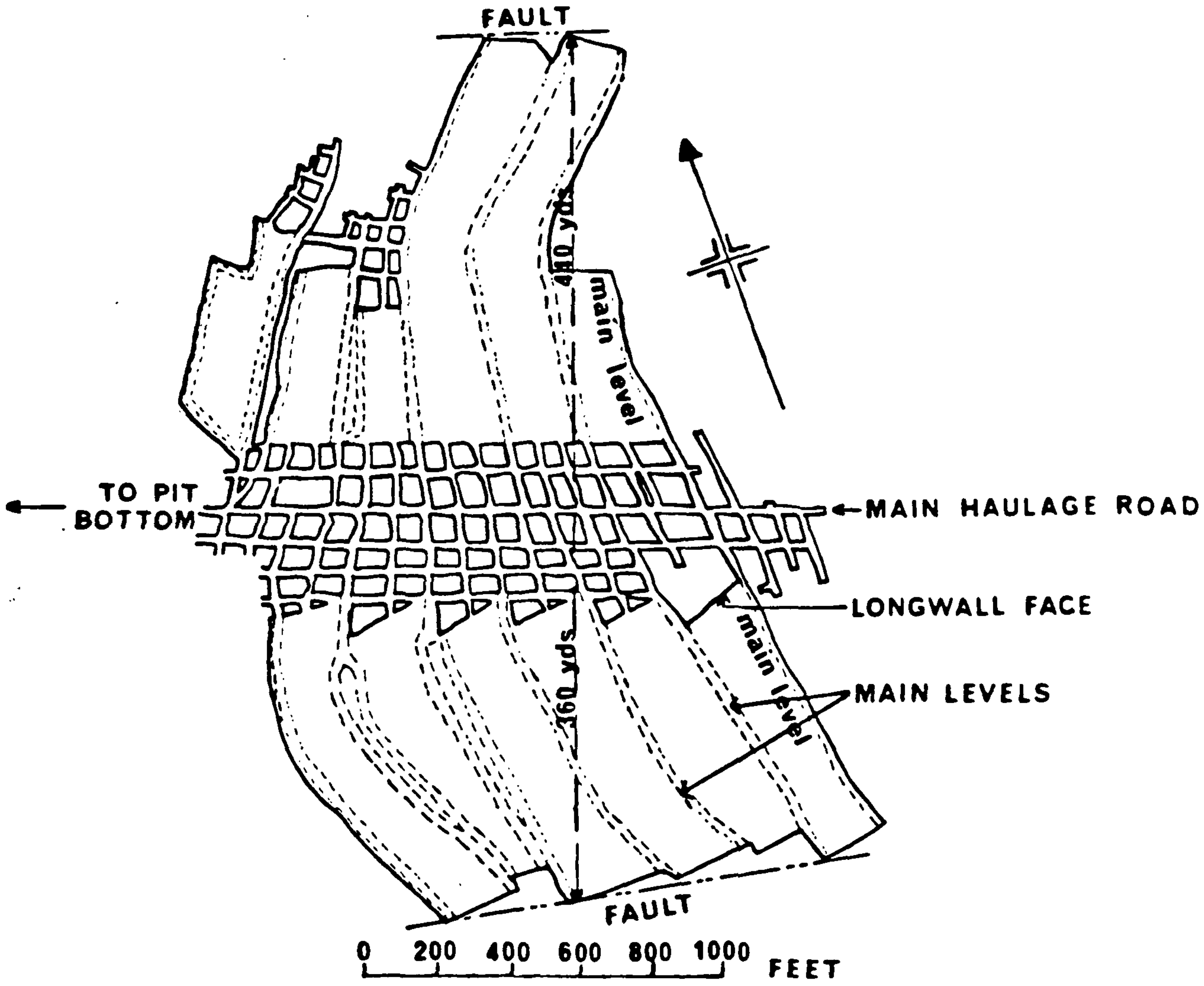
During the mid-nineteenth century the first shale mines were either opencast or inclined shafts driven into the sides of the valleys. Vertical shafts, which required the simplest methods for the pumping of water, were later developed. Upon the advent of the steam-driven horizontal pump, inclined mines became popular, since this new waterpump overcame the difficulties of pumping water up such shafts.[4] During the twentieth century the technological difficulties had, to a large extent, been overcome and the chief consideration in selecting the type of access to a shaft was financial cost. Inclined mines were therefore used when seams outcropped and vertical shafts when seams were buried deep below the surface.[4] One of the most modern shale pits in Scotland, the Westwood pit, was described in detail in the Iron and Coal Trades Review, 1948[8]. It had two vertical, brick-lined shafts, which were sunk in 1948.

2.2 Methods of working

2.2.1 Longwall method

During the first thirty years of the industry, most Scottish shale mines were worked by the longwall method.[2] Two reasons for the initial popularity of this method can be cited: firstly, the surrounding coal mines were mostly worked by this method and miners thus had most experience with it[2,4]; secondly, the longwall method was best suited to thinner seams containing non-oil bearing strata (blaes).[4,12] In these older mines, the advancing face was generally 100 yards long. It was divided into 16-yard portions, allocated to teams consisting of a miner and two helpers.[12] The "miner" carried out the holing (by pick or blasting), propping and blasting; the "filler" loaded the hutches, while the "drawer" conveyed the "hutch" (wheeled tub) to the main haulage. The output of such three-man teams was 6 -7.5 tons per shift, i.e. 2 - 2.5 tons per man.

During the period ca. 1890-1940 little, if any, longwall mining took place, but some experimental longwall mining methods were re-introduced after 1941, to evaluate the usage of coal-cutters, belt-conveyors and other innovations.[13] Two faces, working the Broxburn seam, were longwall-mined in Breich pit until July 1946, when labour shortages brought the work to a halt. The faces were opened on either side of an established "stoop and room" mine. (Fig. 2.1) The seam was 5ft thick and it was clearly bounded at the roof and floor by 1 inch layers of ironstone. A strong shale above the ironstone layer provided the roof with adequate strength. In the initial development, the main haulage road was extended to the full dip of the seam and a gridwork of roadways was developed with main levels running perpendicular to the dip of the seam (Fig. 2.1). Between each of these north-south level roads, longwall faces of an average length of 200ft were formed. The maximum distance between the main haulage road and the longwall face was 440 yards. The shale was worked by undercutting on the floor level to a depth of 3'6", followed by the blasting of two rows of shot holes. The shot holes were drilled by hand-held electric drills. Gunpowder was used in the top row of holes and Polar Ammon gelignite in the bottom row. The shale was then manually loaded onto a shaker-conveyor which ran the full length of the face. A 50 h.p., 15 inch coal-cutter with a 3'6" heavy chain cutter of eleven lines (39 picks) was used for the initial undercut. The face was supported by means of H-section steel props and strip packs which were 13ft wide buttressed by timber "boxes" made out of old railway sleepers. These strip packs were placed 16ft apart and between them chocks were placed which were reset daily.[13]



PLAN OF BROXBURN OIL-SHALE WORKINGS WITH LONGWALL FACES

Figure 2.1

The daily output at Breich pit was 220 tons from each face. The strippers could produce 17 tons each per day and the average output per man employed at the face was 5 ½ tons. The longwall face was divided into 14 foot workplaces ("stents"), where "strippers" were allocated to break up and load the shale onto the conveyors, as well as setting up the steel props.[13]

The cycle of work was arranged into three shifts each 24 hours. The afternoon shift moved the conveyors and chocks and extended the rubble roof support packs. The night shift bored the shot holes, undercut the face, extended the rails and fired the bottom row of shot holes. The day shift then removed the shale and fired the top row of shot holes, removing the resultant shale as well. They also set up the steel supports for the conveyor track.[13]

Caldwell et al[13] reported some difficulties in organising the labour at Breich pit, which was attributed to a lack of "team-spirit" in contrast to stoop and room mines. It was noted that the wear and tear on face machinery was heavier than in coal mines. The fact that 5 - 6 inches of oil-bearing shale was lost in the undercut implied a substantial financial loss which was not encountered in conventional shale mines. There was, consequently, no appreciable reduction in the cost per ton of shale mined during the experiment, despite all the technological innovations.

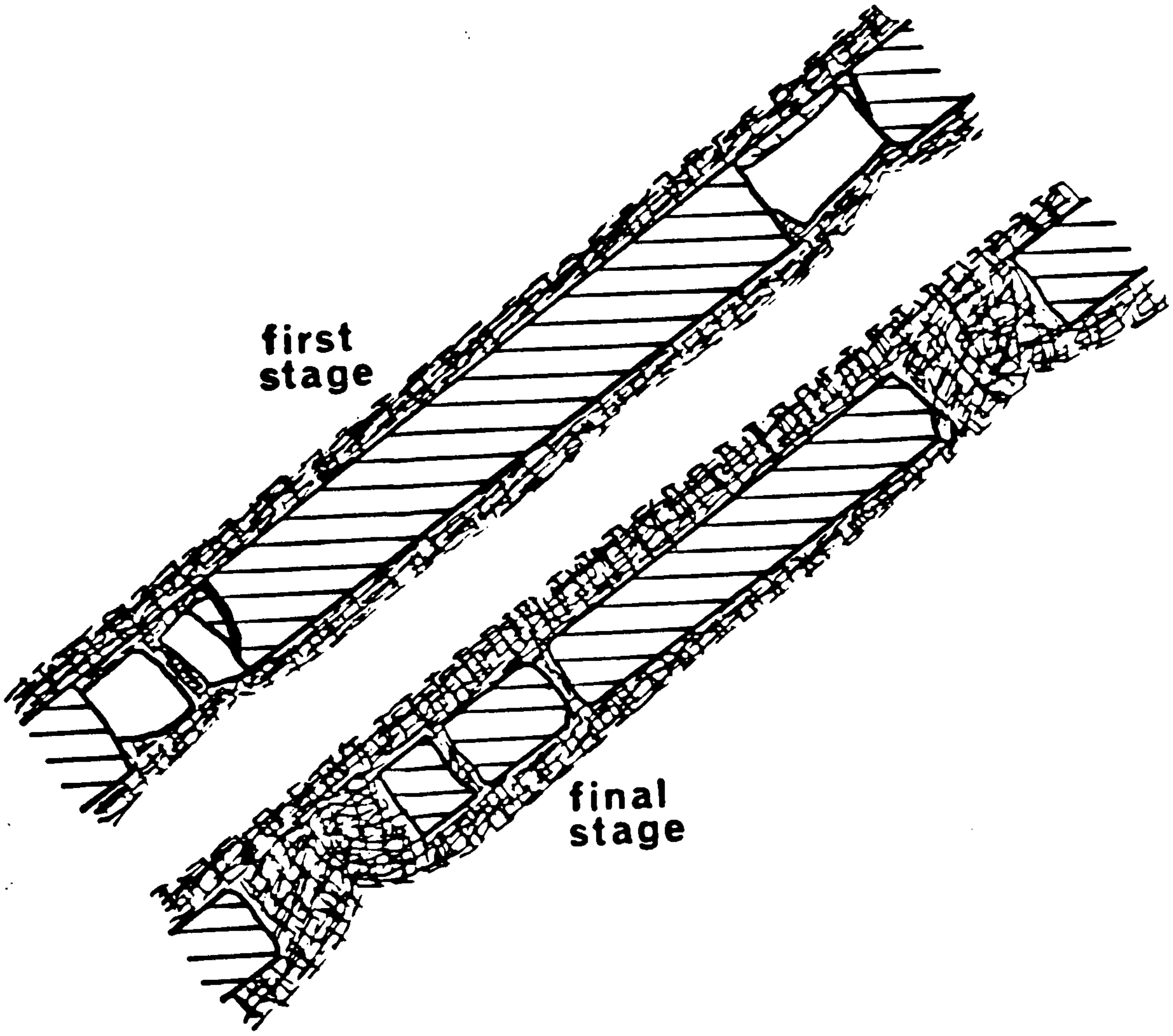
In November 1942 an attempt to work the Fraser seam (at Fraser pit), in a similar manner to that described above, had to be abandoned because of weakness of the roof.[13]

2.2.2 Stoop and Room Mining

This method was most suited to the Scottish shale seams and was used almost exclusively after ca. 1890. In general, development was begun by driving a 12 - 13ft wide main roadway into the seam. Thereafter sections were opened on either side, to develop a gridwork of roadways ("rooms") which were 12 - 13ft wide, with pillars ("stoops") in between. The size of these pillars depended on the depth of the seam (i.e. the weight of the overlying ground), so that at a depth of 120 yds the pillars were 60ft square, while at a depth of 400 yds the pillars were 200ft square. In highly inclined mines, the pillars were made rectangular to prevent "creeping". (Fig. 2.2). In this manner, roadways were fully developed to the mine's boundary or to a large fault; the height of the stoops in the development phase was 9ft, in general.[4,8] The output per man in the phase of development was approximately 5 tons per day.[8]

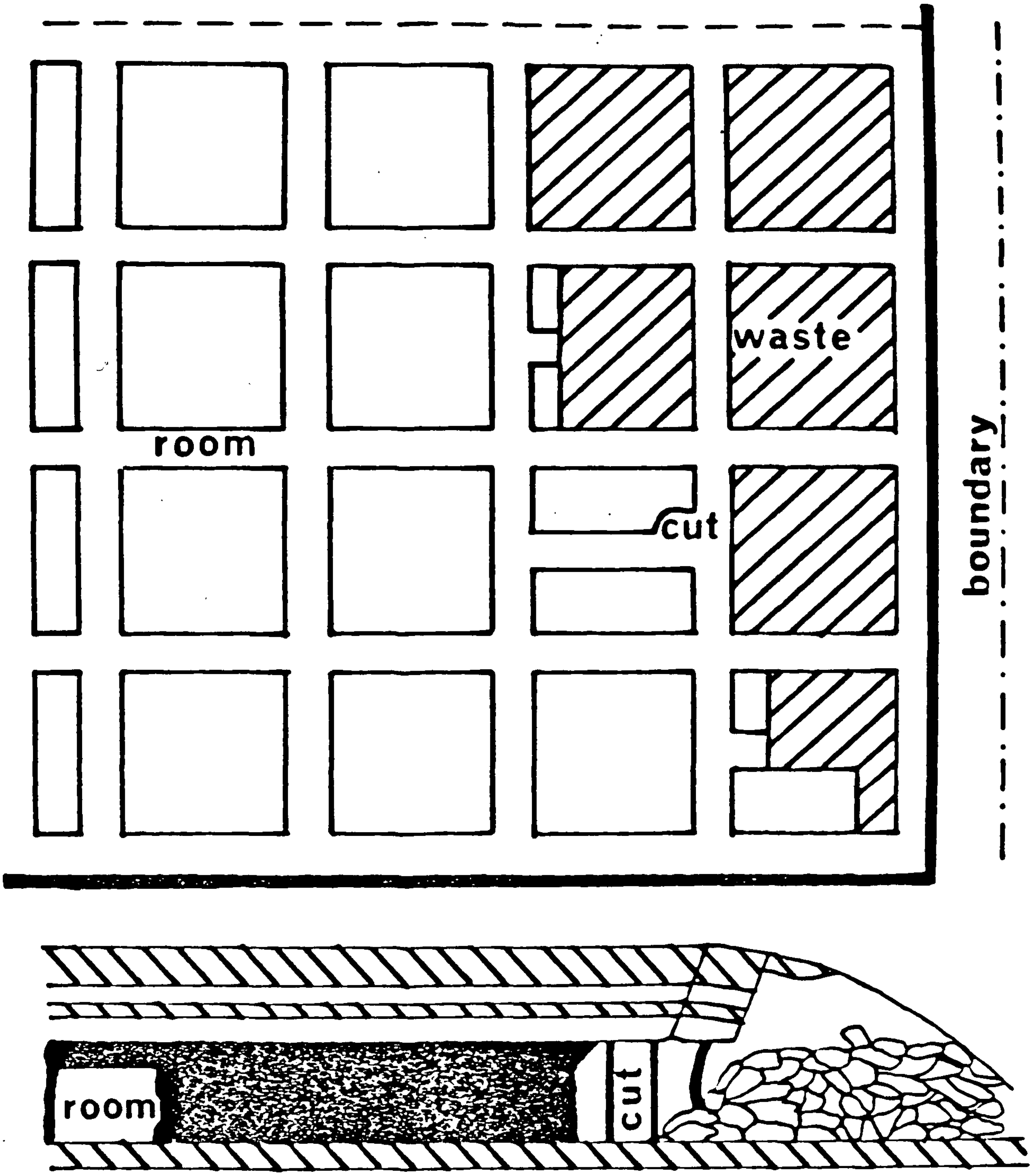
Once the roadways had been fully developed (or the "stoops formed"), extraction of the pillars could commence. If the roof was strong, the pillars were usually split up, by making 12 to 15ft roadways through them, so that a workface was formed.[4] (Fig 2.3) With a weak roof or in an inclined mine, the stoops were removed in small pillars of 13ft square.[9] In this "extraction phase" the roof height was often increased to the full height of the seam, sometimes up to 12 ft. Extraction of the stoop was done in such a manner as to maintain a roof-fracture line of about 45° to the levels.[8] In most instances the recovery of shale from the stoops was about 95%. Usually a fairly clear parting between the oil-bearing shale and the roof and floor could be seen.[8]

As described in Section 1.5.2 above, each work-place at the face was subcontracted to a miner who employed one or two helpers. Undercutting was commonly done by pick-axe and



CREEP OF THE STRATA IN HIGHLY INCLINED MINE

Figure 2.2



STOOP AND ROOM METHOD OF WORKING

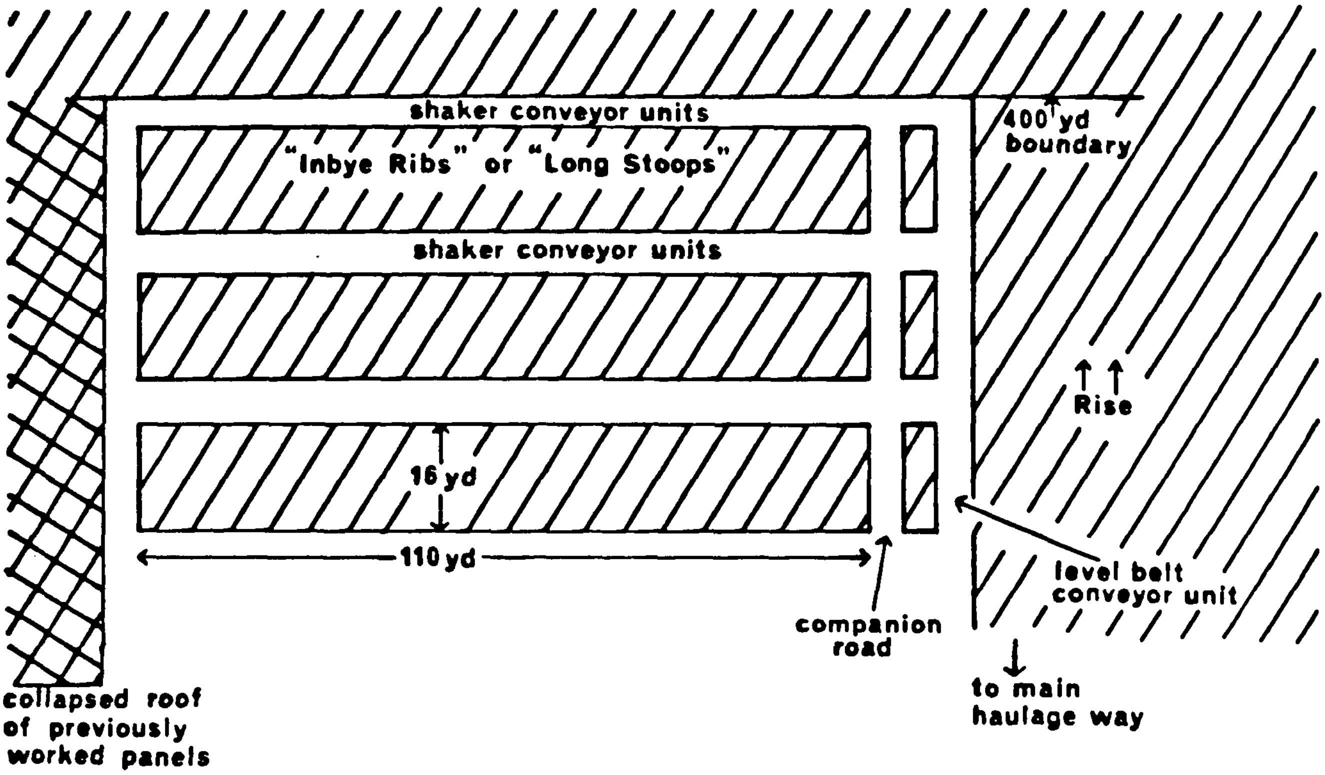
Figure 2.3

shotholes were most often made by means of manual ratchet-drills. Haulage of shale from the face to the main roadway was usually carefully planned so that full hutches rarely had to be pushed manually. Usually a counterbalance technique with ropes and pulleys was used, so that a full hutch would travel down the incline to the main-roadway whilst pulling an empty hutch up the incline (See section 2.3.6 for a detailed description). Haulage at the major roadways was by linkage of hutches onto endless ropes driven by steam, diesel or electric motors and at the main road underground diesel locomotives were generally employed.

2.2.3 "Modified stoop and room" mining

As the result of shortages in the supply of labour during World War II, conveyor belts were introduced into some mines, thereby markedly reducing manpower requirements. This innovation allowed for the development of a radical modification of the stoop and room mining method.[12]

The mine was developed by extending the main haulage roadway to the full dip. This roadway was supported by permanent supports and carried the hutch roadway and pumping column. Hutches were pulled along by endless rope. Parallel to the main roadway, there was a companion roadway (35 yds uphill), which carried the main belt conveyor from the level road conveyors to the hutch loading point. The level conveyors ran in "level" roads which were perpendicular to the main roadway and these extended to the boundary of the pit. (See Fig 2.4). The level conveyor roads were accompanied by parallel companion roads as well. Perpendicular to the level road (and parallel to the main roadway) inbye connective headings were developed, creating a series of "inbye ribs" or long stoops, which were 110 yards long and 16 yards wide. Once these "ribs" had been developed, their total extraction could commence in a systematic manner, working from the boundary towards the main roadway, from the dip towards the rise on six ribs simultaneously. (See Fig.



PLAN: MODIFIED STOOP AND ROOM METHOD OF SHALE MINING

Figure 2.4

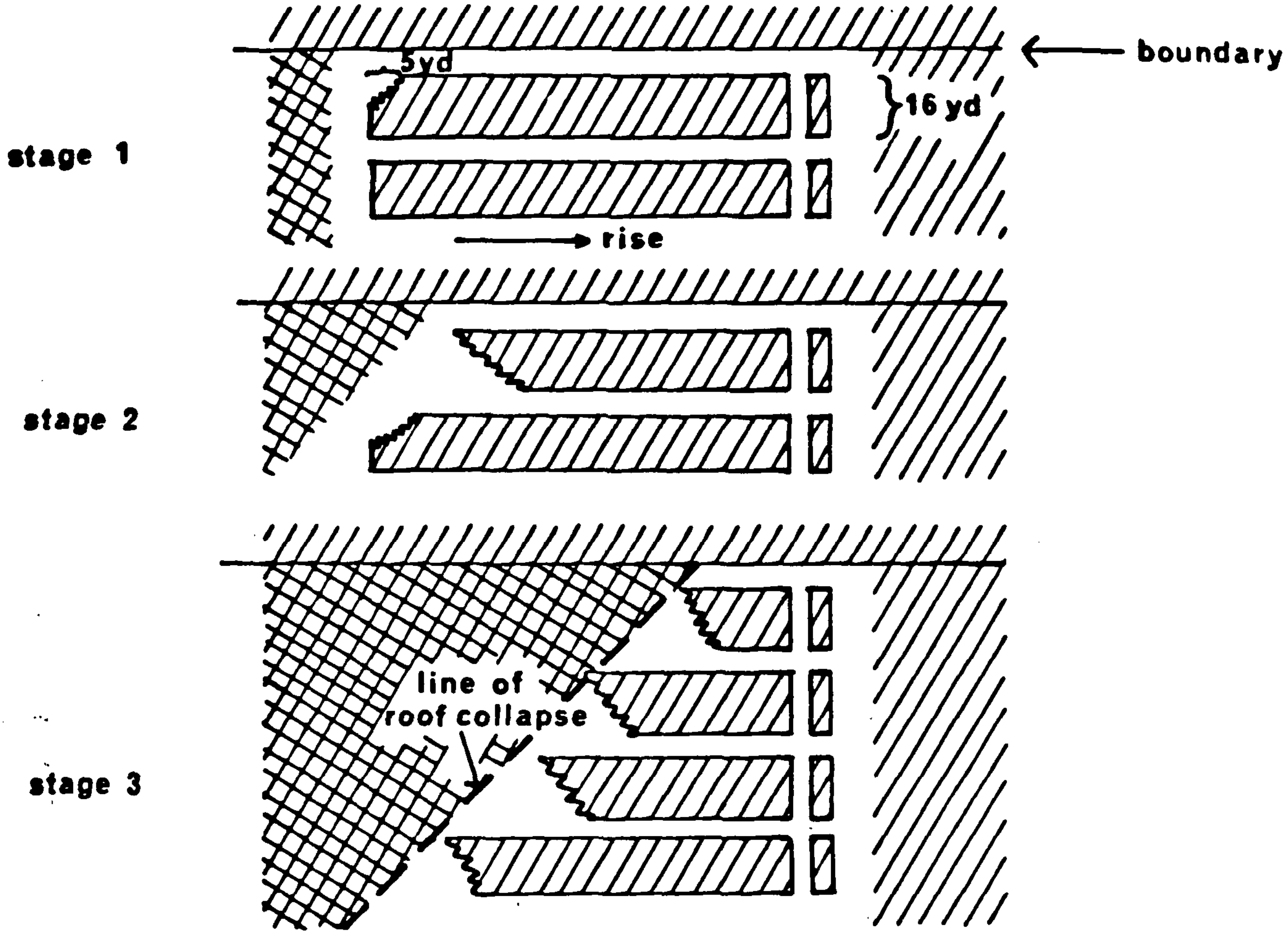
2.5) Shaker conveyor units were used in between the ribs and these carried the shale to the level road conveyor. The working places on the ribs were 5 yds wide and extraction was in stages along each rib so that good control of the roof collapse was maintained. Thus a "retreating" method of extraction was practised until the upper level roadway was reached, when the equipment was moved to develop the next rib. Upon extraction of all the ribs, the next level roadway was driven to boundary, 120 yds to the rise.[12]

This modification of the classical stoop and room method of mining had the advantages of allowing the total extraction of shale, the extensive use of conveyor belts and a significant simplification of ventilatory arrangements (described in Section 2.3.8).[12] The method of extracting the shale was similar to that used in conventional shale mines, using three-man teams at every workplace. Each team was expected to produce 36 tons per shift. This was, clearly, a significant advance over the production in conventional stoop and room mines.[12]

2.2.4 Open cast shale mines

During the period 1900 - 1910 open-cast mining was carried out "fairly extensively" at Philpstoun and, to a lesser degree, elsewhere in West Lothian.[6]

As the result of the labour shortages prevailing towards the end of World War II, a survey was conducted to locate any remaining potential sites for open-cast shale mining. In all, five sites were identified, of which three small ones had previously been exploited. The remaining two were then developed and Caldwell et al gave a detailed account of the workings at Livingston.[6] This site represented an outcrop of the Middle Dunnet seam and was quarried from April 1946 onward. The extent of the outcrop was only 21 acres, with faults at either end. The working was further complicated



MODIFIED STOOP AND ROOM: WORKING THE "LONG STOOPS"

Figure 2.5

by the belated discovery of a preglacial river bed which divided the site into two halves. The thickness of the shale seam varied between 11 and 18ft and the dip varied from 15° at the western to 8° at the eastern boundary. Both workable areas were covered by 8ft of surface deposits, chiefly sand and gravel; the overburden consisted of 50ft of Carbonaceous shale. The maximum depth to the floor of the seam was 65 ft and the ratio of overburden to oil shale at this depth was only 2.5:1. The working format at Livingston resembled the usual practice of strip mining. A tractor scraper and dragline cranelifts were employed to remove the overburden and a tractor bulldozer moved debris. Thus a "face" of approximately 80ft wide was exposed. The shale was won by shotfiring in holes drilled to a depth of 16 -18ft by means of compressed air percussive drills. The size of the shale fragments could be regulated by the spacing of shotholes and by varying the quantity of explosive in each shot hole. During the period 1947 - 1950 the average output was 3000 tons of shale per week. The total workforce at the Livingston quarry comprised 26 men, including six lorry drivers.[6]

2.3 Technical advances

2.3.1 Shot hole drilling

In the early years of the industry (1860's) shot holes were made by means of miners' picks. However, a hand-operated ratchet drill was soon introduced and these were used extensively until the industry closed down in 1962. During the period 1900-1910 electric drills were introduced by several companies.[4,9] These, however, were successful only under ideal conditions and proved unsuitable in hard shales and in workings at steep inclines. In the early 1930's a new type of percussive drill was put on trial, but it also proved to be unsuitable.[9] Evidently, a rotary motion was preferable to a percussive action. A newly-designed cutting bit led to the successful re-introduction of electric rotary drills in Burngrange pit (West Calder) in the early 1930's.[4] These drills were low speed, turning at 600rpm, using a 1½ hp motor. Later, during the period 1941-1946, tungsten-carbide bits were used on the longwall faces at Burgrange pit, with the same type of drill.[13] By 1948 some mines were using Siemens-Schuckert high-speed electric drills, capable of drilling holes to depths of 4 - 6ft.[8] In 1950 it was reported that more than 100 electric drills were in general use in the shale mines.[5]

2.3.2 Shot firing

In the earlier years of the industry, compressed gunpowder was preferred to high-powered explosives (such as gelignite), which tended to cause excessive fragmentation.[9] Gunpowder was said to have a better "spreading action" than high explosives. Safety fuses were used, sometimes in conjunction with Bickfort igniters. High explosive, usually in the form of gelignite, was used when hard beds had to be crossed, or when conditions were wet.[9]

In 1938 it was reported that over half a million shots were fired every year, of which "more than half are charged with gunpowder and the remainder with "high" explosives."[14] On the longwall faces of the Broxburn mines (described in Section 2.2.1) the bottom row of shot holes was routinely charged with 10 - 12oz of Polar Ammon gelignite, while the top row was charged with 1lb compressed gunpowder per hole.[13] This practice was not generally adopted, however, since the same authors reported that blasting at the modified stoop and room mines was primarily with compressed gunpowder.[12]

2.3.3 Mechanical cutting devices

It is on record that attempts were made to use coal cutters in 1878[4] and again during the First World War, when a disc coal cutter was used at Tarbrax.[9] It was found, however, that the shale was too tough and maintenance costs of the cutters were prohibitive of their continued usage, so that, in the latter instance, the experiment was abandoned after eighteen months. By 1938 it was reported by Sneddon et al that no mechanical cutter had proved suitable for prolonged shale mining.[4] Similar comments were made in 1948[8] and, certainly, at the 1950 Scottish Conference, no report was made of the successful adoption of mechanical cutters in any Scottish shale mine. As was mentioned in Section 2.2.1, coal cutters were briefly in use in an experimental longwall mine.

2.3.4 Power supply

Until the introduction of electricity, steam was the only source of power for winding, haulage, water pumps and ventilation fans. Coal was used as fuel to generate steam and some shale mines deliberately extracted coal from seams overlying the shale for this purpose. The Baads colliery, at which the Hurlet coal seam was mined, was owned by Scottish Oils Ltd., and supplied fuel for mines, retort works and refineries.[4]

Electrical power was first introduced, on a small scale, into the industry in 1879, but its adoption in mines occurred much later. The first completely electrified mine in Scotland was opened in 1903 by the Oakbank Oil Co., at Duddingston, near Winchburgh.[4]

By 1938 all plant (except a few winding engines) in Scottish shale mines was electrically operated. As the result of the consolidation of the industry, power stations at retort works distributed electricity to mines and other retort works through a common grid.[4]

2.3.5 Winding

During the last century, winding in vertical shafts was almost invariably by means of horizontal coupled steam engines, with parallel drums. In 1904 the first electrical winding motor in Scotland was installed at No.1 Pit, Cobbinshaw, Tarbrax. This was a 200 hp motor, using direct current and was connected directly to the winding drum shaft. The design was known as the Ilger system, comprising a 3000 volt induction motor, a variable voltage D.C. generator, an exciter and a heavy fly-wheel.[4,9] A similar system was installed at Breich pit in 1912.[4] During the next few decades, most mines installed electrical winders, so that by 1950 only two pits were still using steam winders, viz. Westwood pit and Hopetoun No.35 pit. After 1935 all winders were of the A.C. type and were between 170-325h.p. In 1950 it was reported that "complete electric winding equipment are used in two inclined shafts, No.6 mine, Philpstoun, and Hermand mine, the latter not at present in use, and in three vertical shafts, Breich pit, Burngrange pit and Fraser Pit."[5]

2.3.6 Underground haulage

The marked folding of shale seams demanded careful consideration of underground haulage systems to minimise cost and maximise safety. A variety of methods was developed and these will briefly be described in this section.

Gravity

Since the majority of shale seams were inclined, the shale miners adopted four standard methods of gravity-assisted haulage.[4,9]

a) "Cousie Braes" - two (or more) hutches running on parallel rails were linked by a chain passing over a pulley near the face; the descending full hutch pulled up the empty hutch;

b) "Cuddie Braes" - similar to (a) above, except that the hutch was balanced by a smaller, loaded hutch on a narrow gauge rail (termed a "cuddie") to pull up the empty shale-hutch;

c) "Cut Chain Braes" - a method of gravity haulage by which counterweight systems as described above were used, but with the refinement that hutches could be drawn up (or down) part of the way, from one level to another;

d) Carriage haulage - a system, similar to the "cuddie brae", but instead of linking the full hutches directly to the chain, they were placed on specially designed carriages.

Where gradients were favourable, chutes were sometimes used to carry the shale from the face to the nearest hutch loading station.[4]

Horses

Horses were in general use throughout Scottish shale mines, since it was found that one horse could do the haulage for three work places as against the requirement of one man for each workplace. Stables were well maintained in special cavities constructed underground. The presence of ponies in some pits was recorded as late as 1948.[8]

Steam-driven haulage systems

Haulage engines were all steam-driven prior to the introduction of electricity into shale mines (during the first decade of the 20th Century). These engines were used to operate one or two mechanical haulage sytems viz. direct (or "dock") haulage, or endless rope haulage.[9] In 1938 the continued usage of steam-driven haulage was reported in at least one mine, No. 26 of Polbeth, West Calder. In this report it was stated that the system operated by counter-balanced hutches, assisted by the steam haulage, and that such systems were preferred where gradients exceeded 22°.[4]

Electrically-driven haulage: belt-conveyors

With the advent of electricity, mechanical haulages were widely adopted in many Scottish shale mines during the first decade of this century.[4] Such belt-conveyors were, for example, extensively used in the "modified stoop-and-room" mining technique described in Section 2.2.3 above. Indeed, it is doubtful that this mining technique could have been so profitably adopted without their application.

Diesel locomotive haulage

The first underground diesel oil locomotive was introduced at Burngrange pit in the late 1930's. Being 12 h.p., it was capable of handling about 30 hutches per run on roadways which were driven at a gradient of 1 : 120 in favour of full hutches.[4,8]

2.3.7 Water pumps

The earliest mines were relatively shallow and water pumping did not pose a serious problem. Until about 1882 pumping was generally done by means of "bucket" or "plunge"(ram) pumps, which were situated at the bottom of vertical shafts; these were worked by wooden rods. These pumps had an average lift of 180-270ft.

The first large-scale pump, a grass-hopper type, was installed by the Mid-calder Oil Co., in 1876. It had a cylinder 62 inches in diameter and a 10ft stroke. In 1882, a similar pump was erected at No.11 Pit, Gravieside.[4] Later, direct-acting steam pumps were installed for underground use in dipping mines. The most common type was the double-acting ram pump, which required the installation of underground steam pipes.

The advent of electricity led to the design of treble ram pumps, and multi-stage centrifugal (or turbine) pumps.[4,9] By 1950,electrically-driven turbine pumps were predominantly used.

2.3.8 Ventilation

By law all shale mines were required to have two shafts, the second being primarily used for ventilation purposes, and known as the "upcast shaft". In the early years of the industry, circulation of air was accomplished by the construction of a "cube" or furnace at the bottom of the upcast shaft. This, however, posed a fire-hazard and, when one such furnace caused an underground fire in the late 1860's, this mode of ventilation was abandoned. Thereafter steam-driven mechanical fans, of the Guibal type, were installed.[4]

By 1927 four types of fan were in general use, namely the Guibal, Waddel, Sirocco and Capel fans.[9] The latter two were high-speed and were usually driven by electric motors, while the former were still sometimes driven by steam engines.

The fresh air was channelled through the mines to the working faces by means of air-tight doors and the erection of cloth screens. In steep workings additional fresh air was channelled to the face by means of hand-or electrically-operated fans, using ducts made of wood (known as "rhones")[9] or canvas.[12]

2.3.9 Lighting

Scottish oil-shale mines were, on the whole, considered to be at low risk for gas explosions and open carbide lights were commonly used before the advent of electric lighting. Where methane gas was detected, men were supplied with flame safety-lamps and, later, with electric cap-lamps.[4] By 1948, mixed lighting methods were still in use; e.g. at Burngrange pit, open lamps and locked safety lamps were used, whereas at Westwood pit electric diffused incandescent lighting had been installed.[8] Experience had shown, however, that mains lighting near the face could not stand up to the blasting and therefore cap-lamps were the only source of lighting used by faceworkers.[12]

CHAPTER 3

SAFETY MEASURES ADOPTED IN SCOTTISH SHALE MINES

3.1 Statutory Controls

The shale mines in Scotland were regulated by legislation which was primarily drafted for the coal mines of Britain e.g. the Coal Mines Regulation Act of 1887, the Coal Mines Act of 1911 etc. Thus matters appertaining to safety and health, including the management of mines, conduct of all persons in and about them, the lay-out of workings in respect of shafts and outlets, ventilation, support of workings, transport, use of explosives, electricity, machinery and lighting, first-aid, rescue work and fire-precautions were all controlled by law and monitored by mine inspectors. All ignition of firedamp had to be reported, by law, to HM Divisional Inspector of Mines, whether or not persons were injured; these occurrences were then the subject of careful investigations. HM Inspector of Mines also required reports of all injuries, fatal or non-fatal, at mines.[14] In this manner close monitoring of possible malpractices could be maintained.

3.2 Safety due to careful planning

Winstanley in 1938 made the point that a sense of responsibility in the individual was more important in the prevention of accidents than the drafting of regulations[14]. He asserted that "a study of typical cases of serious accidents from falls of grounds indicates very clearly that safety depends to a very large extent on the skill, sound judgement and care on the part of each workman, and the direct supervision exercised by officials who inspect all working places at least twice every shift, and, further, that safety depends far more upon the personal factor than upon regulations."

No doubt the fact that workplaces at the face were sub-contracted for extraction to a face-man who was responsible for the planning of extraction, blasting, supports and safety of his allotted face contributed to the success of the system. Caldwell in 1950 quoted figures that suggested that the "modified stoop-and-room" system was even more successful in promoting safety, due to a heightened awareness of the need for safe mining practices.[12]

3.3 Protective Equipment

It would appear that the adoption of hard-hats, goggles, safety boots and gloves was slow to gain popularity in the shale mines. Winstanley, for example, stated that at the end of 1937 there were 625 hard hats in use in the Scottish shale mines[14]. He indicated that, contrary to practice in the USA and Canada at the time, Scottish companies were not insisting on the wearing of hard hats, but relied on persuasion only.

The adoption of respiratory protective equipment was not popular. Evidently the dust generated by the usage of electric drills (for shot-hole boring) caused some concern and a lecture was given on the topic of face-masks at Pumpherston's No.6 mine in the early 1940's. A few men were thus persuaded to wear aluminium face-masks which used muslin disposable filters, but this practice was not widespread.

3.4 Baths and first-aid stations

A report in 1948 stated that "at most of the works and mines modern baths have been installed, and run in conjunction with each is a fully-equipped ambulance room for first aid treatment. Bath attendants are fully qualified first-aid men."[8]

3.5 Dust suppression

Dust in Scottish shale mines was not regarded as being harmful to health, nor was it recognised as being present in excessive quantitites. There is no record of attempts having been made to practise dust suppression, apart from good ventilation which was primarily aimed at removing the gunpowder smoke and fumes resulting from blasting.

CHAPTER 4

HISTORY OF RETORTING TECHNOLOGY

4.1 Introduction

The first recorded attempt to extract oil from bituminous substrates was that described by Becker and Serle in their Patent No. 330 issued in England in 1684, for the production of "oyle from a kind of stone". The earliest oil-shale industry was founded almost two centuries later, in France, where the "Selligue process" was installed in 1838.[2,17]

The first attempt to extract oil from bituminous substrates by a Scot was in 1781. In that year, the 9th Earl of Dundonald registered a patent for a process to extract tar, pitch and oil from coal, using masonary retorts and wooden condensers.[18] However, it is generally accepted that the inventive Glaswegian, James "Paraffin" Young, was responsible for launching the Scottish shale-oil industry. Not only did he design a successful retort in 1850, but he also set about energetically exploiting the deposits of cannel coal (syn. Boghead Cannel coal, torbanite) in the West Lothian district of Scotland. These activities stimulated interest in the rich deposits of oil-bearing shale in that region. It is usually said that the first recorded commercial retorting of Scottish shale took place in 1859, when Robert Bell discovered oil-shale deposits on his leased land in the Broxburn district. He arranged for it to be retorted by Faulds, of Glasgow, who quickly built a number of retorts; by 1862 Faulds had erected 36 horizontal retorts for the distillation of shale-oil.[19] Redwood,[20] in his detailed treatise, stated that there were 52 oil works in operation in 1850; it appears likely, however, that many of these were engaged in retorting cannel coal.[18] The supplies of cannel coal were very low by 1875, after which very few cannel coal retorts remained in operation. The intensity of the competition for a place in the shale

industry is reflected in the fact that between 1850 and 1896 there were ca. 60 shale retort works in existence.[20]
In general, retort works were placed at a convenient site near mines owned by the relevant company, with due consideration of such factors as the need for an abundant water-supply and space to create the "bings" (tips of spent shale). The raw shale was usually brought to the works by rail and put through a crusher to fragment the larger pieces. The crushed shale was transported in man-handled hutches to the tops of the retorts; after 1940 conveyor belts were used at some works. The more modern retorts were in continuous operation and the spent shale was constantly extracted from the bottom of each retort, being dumped into a second set of hutches which were used to tip the spent shale on the tops of bings. A retort works required a large and steady supply of steam, which was obtained from the shale retorting process itself, and/or coal boilers and/or from the heat retrieved from the precipitation of oil vapours. Some retort works were situated adjacent to the refinery belonging to that company, whilst others had to transport the crude oil to a refinery some distance away. In 1925, near the peak of the industry's productivity, the number of persons employed in the retort works and refineries was 2,567, whereas 4,315 were employed in the mines (total 6882).[3] In 1960, before the large-scale redundancies in anticipation of the closure of the industry, the total number of employees (mines, retorts and refineries) was 2,134. (Scottish Oils Ltd: Ledgers of numbers employed. BP (Grangemouth) Archive document No. 050670 1956-1963).

The evolution of retort technology stemmed from the need for innovation by the industrialists in order to meet the financial constraints and demands of the market place. Initially, retorts were small and more labour than capital-intensive. Considerations of the cost of heating fuel and labour led to larger, vertical (gravity-fed), continuously-operating retorts. Different designs, to improve heat transfer and fuel economy, led to the use of shale products for heating, grouping together of retorts, steam injection, air injection and progressively larger retorts. The introduction of electricity into industry led to automatic retort-charging devices and a variety of other labour-saving adaptations. Competition from the petroleum oil industry led to developments which were specifically aimed at maximising the yield of by-products such as sulphate of ammonia and wax. These and other considerations that had a bearing on the technological developments are outlined in Tables 4.1 and 4.2.

TABLE 4.1: MARKET FORCES AND RETORT TECHNOLOGY

1850	- Burning oils and lamp oils required - peak price (1860) 3s6d/gal Batching oils for spinners, weavers and rope-makers required Cleaning and lubricating oils for machinery required Horizontal retort : cracked heavier oils and produced good quality burning oil.
1859	- Edwin L. Drake struck oil in Pennsylvania Kerosine exported to Scotland, causing burning oil price to fall to 1s/gal in 1865 - Vertical retorts to produce heavier oils and wax
1870	- Peruvian guano supplies diminished - Price of sulphate of ammonia rose - peak price £22 per ton in 1880 - Vertical retorts with double-phase heating to maximise sulphate of ammonia yield
1894	- Invention of Pumpherston retort (and similar designs) - shale industry became independent of coal industry
1901-06	- Excise duty imposed on automobile fuels
1914	- Royal Navy converted from coal to oil: World War I - Shale-oil industry gained strategic value - Oil product prices and labour costs increased markedly
1910 +	- Motor car industry - Market for motor-spirit led to resumption of cracking
1918	- Consolidation of the Industry - Scottish Oil Agency was formed - Finance Act of 1918 relieved indigenous light hydrocarbon oils of a portion of excise duty. (See Table 4.2).
1921-27	- Finance Act (1918) preference withdrawn
1928	- Finance Act (1918) preference reinstated
1930	- Invention of compression ignition (diesel) engine
1938	- Adoption of air-injection into retorts
1940's	- Alkyl sulphate detergent from shale oil olefins invented - First production plant established in 1948
1941	- Westwood retort works took over all retorting
1962	- Government announced their intention to withdraw preferential excise

TABLE 4.2: Preferential duty enjoyed by indigenous gasoline and diesel oil - per imp.gal.

Year	English shillings and pennies
1918	6d. (20s = £1;12d = 1s)
1919	6d.
1920	6d.
1921-1927	Nil
1928	4d.
1929	4d.
1930	4d.
1931-1937	8d.
1938-1949	9d.
1950	1/6d.
1951	1/10½d.
1952-1955	2/6d.
1956	3/6d.
1957-1960	2/6d.
1961-1963	2/9d.

4.2 Retort designs

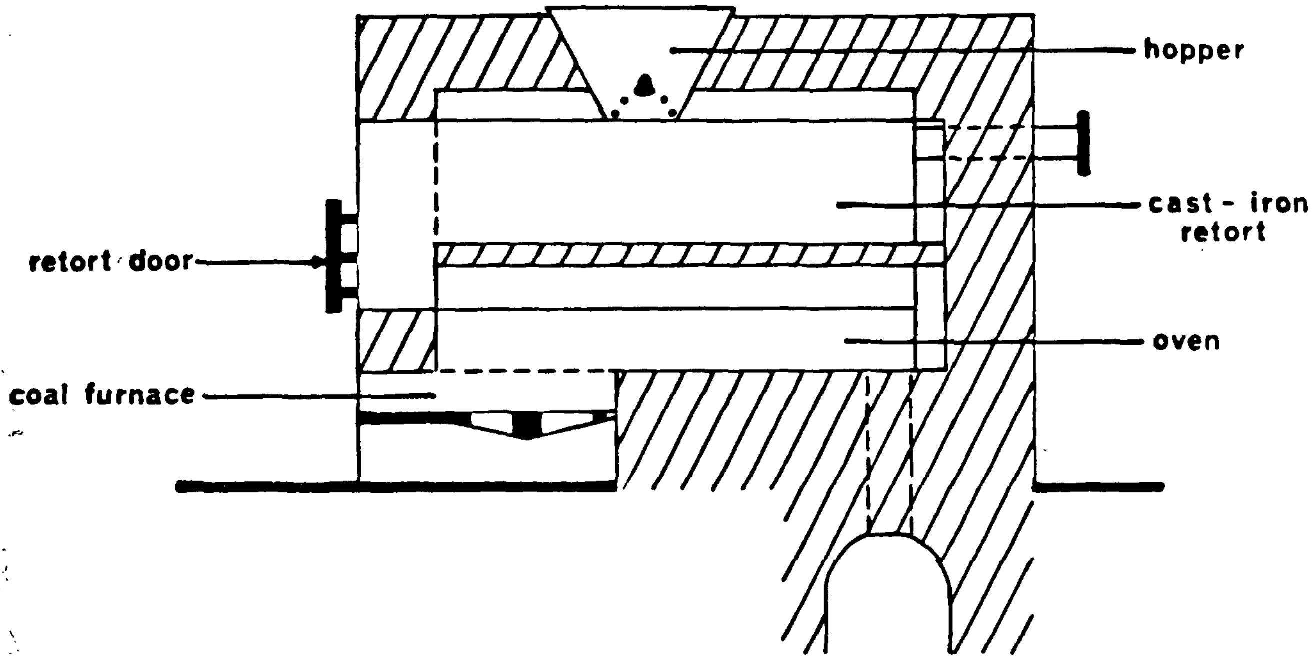
This section is devoted to a detailed description of retort designs, in their chronological order. Although they were modelled on the coal-gas retorts which were in common use in the mid-nineteenth century, shale retorts differed fundamentally in that they required low-temperature distillation to minimise hydrocarbon fracturing. The aim was to produce a maximum volume of oil with as little permanent gas as possible. Thus, shale retort designs were initially aimed at achieving even heat at low cost. Later the attainment of large continuous throughputs became an additional objective.

4.2.1 Horizontal retorts

The first retorts that were patented and used by James Young were D-shaped horizontal gas-retorts, used for retorting cannel coal (Fig.4.1).[20] They were fed by a rotating screw inside the retorts. Apart from Young's retort, a number of other designs were used, of which Bell's and Cowan's retorts were popular: these had the advantage of being cast in two sections. Retort lengths varied between 9-10ft and they were generally about 2'6" wide and 1'3" high.[21]

In his treatise, Redwood[20] stated that 52 oil works were in operation in 1850 and in his exhaustive list of Retort Work Facilities, he makes mention of 758 individual horizontal retorts that were in use during the years 1860 and 1873. This figure is an underestimate, since the presence of horizontal retorts elsewhere was alluded to in the same list, but not enumerated. Also, the facilities in operation during the early 1850's were not included in the list. Clearly, horizontal retorts were used in large numbers by several companies before the advent of vertical retorts. They possessed the advantages of being inexpensive and easy to construct, thus satisfying the requirements of the fledgling industry which lacked any form of centralisation.

Horizontal retorts were generally charged through an end door which had to be luted with fire clay before being closed. The charge consisted of 500-800lbs of shale (or cannel coal), although some had the capacity to take 5000lb loads. They were intermittently charged and discharged by manual shovel and heated in brick ovens by coal fires. The resident time was usually 16-24 hours.[20] Steam injection was seldom or never used in horizontal retorts.[22] Redwood[20] quoted figures based on "the average of a large



HORIZONTAL RETORT

Figure 4.1

number of determinations made on the working scale" which showed oil yields of 34.2 gallons per ton of shale (compared to a Kirk-type vertical retort yield of 39.79 gal.). The more intense heat in the horizontal retorts tended to fracture hydrocarbons, thus yielding products in ratios different to those obtained from vertical retorts (see section 4.3). The control of their heating rested in the hands of the firemen, a variable factor which was later counteracted by steam injection in vertical retorts. Despite their disadvantages, some smaller works continued to use horizontal retorts until 1880 and inventors continued to experiment with means of improving their cost-effectiveness by means of mechanical discharging mechanisms[20] and improving heat distribution for example by rotating the retorts[18]. One important modification was the addition of a hopper fitted on top, to facilitate loading[18].

4.2.2 Vertical retorts

The advantage of the vertical retortdesigns can be summarised as follows: they were gravity-operated, thus requiring less labour to load and discharge; they could, potentially, operate continuously, thereby handling larger volumes of shale with less heat wastage; arrangements could be incorporated for an efficient, controlled heat distribution, despite a marked increase in size; the controlled descent of shale through zones at different temperatures later permitted the sequential extraction of oil and nitrogen (ammonia) to maximum advantage; the later refinement of air injection resulted in the combustion of residual carbon in the shale as an economical heat source; the incorporation of sophisticated heat-exchanging mechanisms was possible, whereby the cold shale was heated while piped oil vapours precipitated within the upper portions of retorts; the principles of mass-production could be introduced with vast banks of retorts being served by common charging and discharging mechanisms.

Lowe & Kirkham's retort and later modifications.

According to Conacher[18], the first vertical retort that James Young used (in circa 1852) was based on a gas retort, designed by Lowe and Kirkham and patented in 1839. It was of cast-iron, and, according to Conacher's description, about 8' high, with a diameter of 1'3" and 1'10" at top and bottom respectively. These retorts were set up in pairs, each protected by a brick screen from the direct heat of the furnace set between them. The charge entered through a valve arrangement at the top and small quantities were drawn off intermittently through a water-seal at the bottom. The gas outlet was at the bottom, so that all vapours had to pass through the hottest zone to augment the yield of permanent gas at the expense of the tars. With small modifications to this basic design these retorts continued in use until 1885.

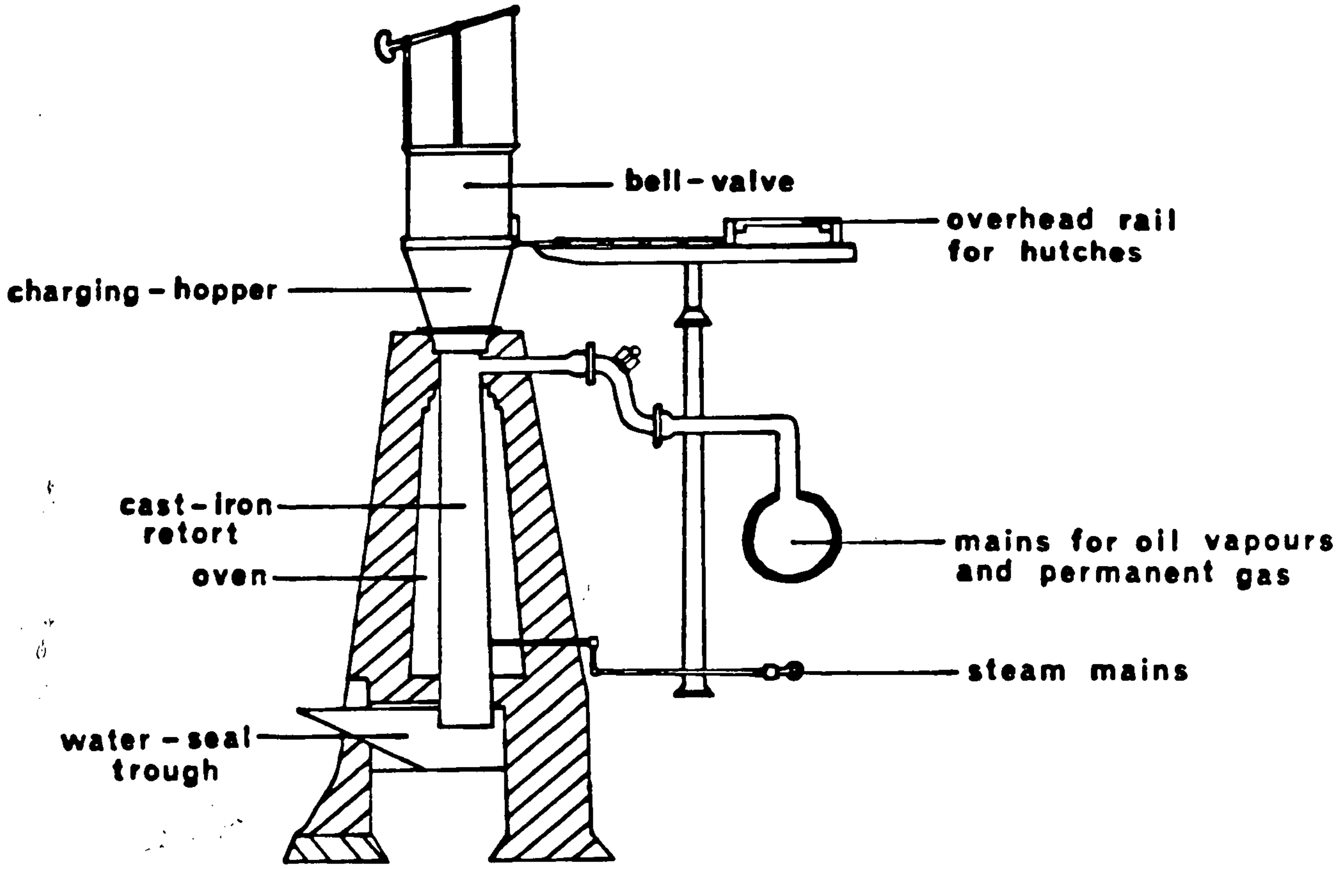
James Young's own early vertical retort design consisted of three cylinders of cast-iron, about 18 inches in diameter and 10-11 feet high. These cylinders stood in a fire-chamber, applying external heat to all three by coal fire. Since heating led to the expansion and fusion of shale fragments, there was a tendency for the cylinders to become congested. Young overcame this problem by designing a cast-iron retort with a tapering cylinder which expanded downward and he also fitted a slowly rotating helical screw. This design met with some success and remained in use for some 6 years.[20]

In 1867 William Young patented a retort which was used for many years at Oakbank Works (Young and Brash's Retort, 1867). It was eliptical in cross-section, wide for its length and had a double casing, thus emphasising the requirement of low-heat exposure to prevent cracking of the heavier oils. The retort was encased in a fire-brick oven[23].

Kirk's retort

A.C.Kirk contributed an important advance by designing a retort with an elliptical cross-section which was much larger at the bottom than at the top (Fig 4.2). This design had two advantages; firstly, it created a larger surface for external heat application and had better heat distribution properties; secondly, it eliminated the need for mechanical agitators. The bottom of this retort was under water, a feature which actually hampered the discharge procedure. Charging and discharging were done in small quantities intermittently, "every hour or so".[23] Redwood reported a series of experiments which compared the performance of horizontal and Kirk retorts and found that the latter were not only more economical to operate, but also gave a larger yield of crude scale (See section 4.3) which increased the profits substantially.[20] The horizontal retorts, however, were superior in their yield of naphtha and burning oil. Clearly the lighter fractions of oil were being cracked into permanent gas in the vertical retort. It was noted that the injection of steam at the bottom of the retort resulted in "a great uniformity of production" and "the quality of the oil was not greatly at the mercy of the fireman".

Operation of this retort was, briefly, as follows: the funnel-shaped hopper on top of the retort was filled by means of hutches which ran on an overhead rail. The hopper emptied into the retort and the escape of fumes and gases was prevented by a ball-valve mechanism. At the bottom, the retort was sealed in a trough of water. A coal-furnace, built in between six retorts - three on each side - supplied heat externally. Steam was injected at the base of the retort. These retorts remained in use until 1880.[24]



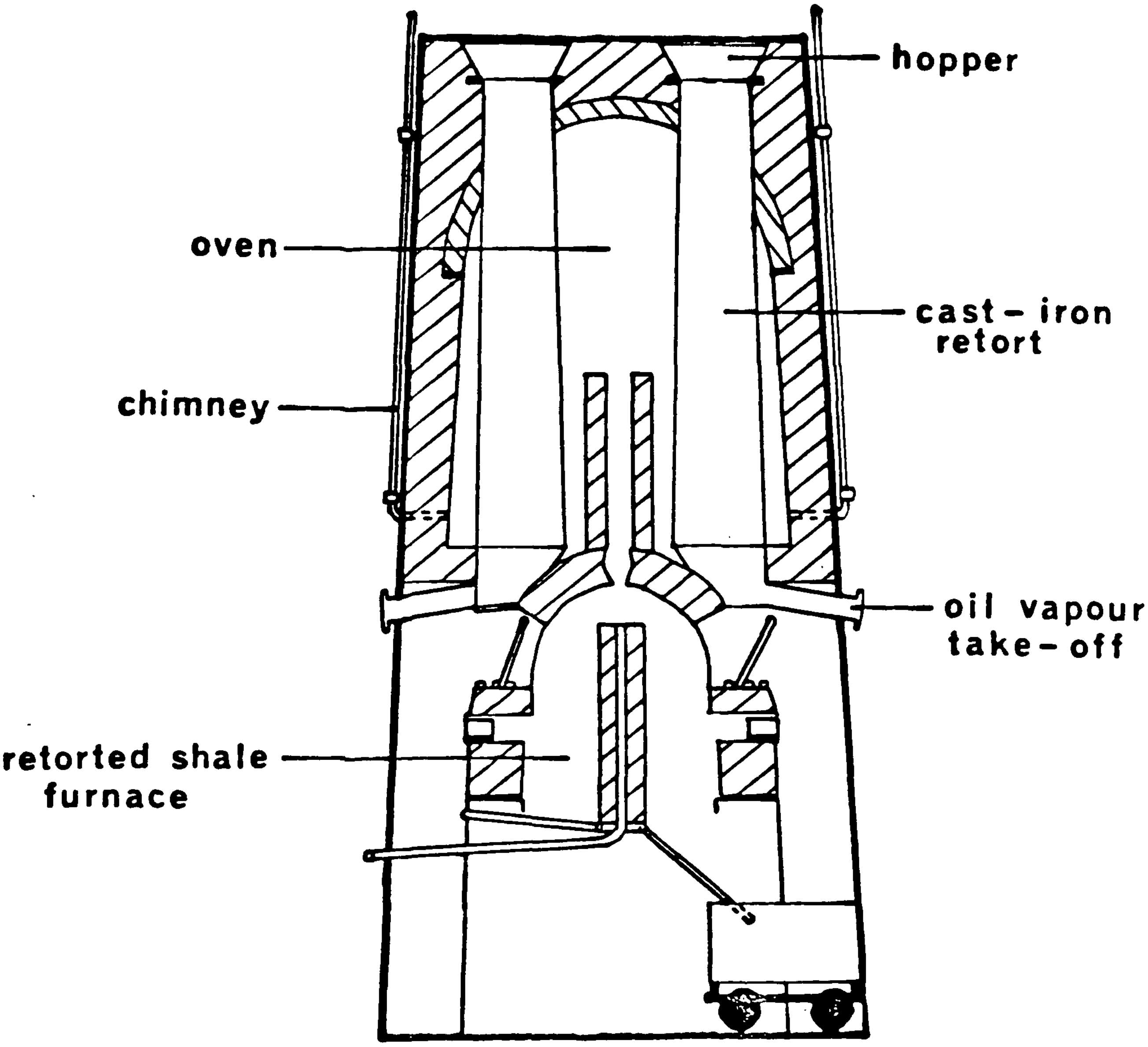
KIRK'S RETORT

Figure 4.2

Henderson's retort

Norman M Henderson patented his retort (also known as the Broxburn retort) in 1873 (patent no 1327)[19,25]. They were used at a number of facilities, including Broxburn, Oakbank and Roman Camp and remained in use until 1892. The chief advance embodied in the retort was the burning of "spent" shale as an additional source of heat. Earlier designs by W Young, Scott and Stephens (1872), as well as McBeath (1867) had pioneered this idea but the retorts concerned were not commercially successful for various reasons.[20,22,23] Henderson's design was for a large retort with a furnace at its base. "Spent" shale was dropped into the furnace where, under conditions of a plentiful air supply, the residual carbon content of the shale (12%) was combusted (Fig 4.3). This resulted in a 50% reduction in heating-fuel requirements, as compared to previously used vertical retorts[20].

Henderson's retort had other innovations as well. It was the only one in general use in which the oil vapours were extracted at the bottom, for it was believed that this would have the effect "of partially purifying them and giving a better quality of oil".[20] The retort dispensed with the cumbersome water-seal at the bottom (which hampered the discharge procedure in its predecessors) and discharged directly into hutches.[20] The application of steam in this retort had a great effect on the quality and quantity of the oil yield.[18] Thus, not only were the labour requirements reduced by one-third (compared to previous retorts), but the products yielded were substantially increased by this design. These economic advantages were so successful that the Broxburn Oil Co., which began to operate in 1878 with only Henderson Retorts, could repay its shareholders' capital in the first four years of its existence.[18] Henderson's retort was also exclusively in use at Burntisland and Linlithgow works. Some were also installed at Oakbank, Addiewell, Dalmeny and Uphall.[23]



HENDERSON'S RETORT (1873)

Figure 4.3

The retorts were made of cast iron with an elliptical cross-section and were placed in groups of four enclosed by a firebrick oven. They were 15' long and 12" x 18" in diameter. The oven was heated by two shale-fired furnaces which were filled intermittently from the bottom of the retorts. The products of combustion of these furnaces were carried upward in a flue which opened in the oven and were then circulated downward to enter the iron chimneys. A carefully constructed valve arrangement at the bottom allowed the shale to be dropped from the bottom of the retort into the furnace and, after combustion, into a hutch.

The retort, which took a charge of 18cwt, was loaded from above by overhead hutches which filled a rather shallow hopper. Initially, a coal fire was built in the furnaces to start the process, after which the furnaces were filled by emptying one of the four retorts every four hours. Permanent gas derived from the retorting process contributed as fuel. Coal supplementation was still required, on average about one quarter to 2cwt per ton of shale,[21,22]: this was 50% less than that required for the Kirk retort[20]. Superheated steam was injected into the top of the retort[22]. Each retort had a throughput of 25cwt of shale per day and the residence time was 17 hours per load.

In section 4.3 it will be seen that the retort had a better fractional yield than the Kirk retort, although its total yield of crude oil was not greater. A disadvantage was that it gave a 50% lower yield of ammonia liquid than the Kirk retort. Ammonia had become recognised as a marketable commodity in the late 1870's, when agricultural fertilizer in the form of Peruvian guano became in short supply (see Table 4.1). Thus efforts were made to increase the nitrogen extraction in this retort by increasing the heat after the oil had been distilled off. Of course, the retort was not designed for nitrogen extraction and the fluctuations in temperature greatly shortened the life of the retorts. Redwood also criticised its suboptimal usage of permanent gas for heating and his experiments indicated that the inlet of permanent gas should have been located above the spent shale and not below it, in the furnace. [20]

Beilby's retort

In 1881 G.T. Beilby patented a retort which sought to meet the requirement of heating the shale in two phases - a "cooler" phase to maximise oil extraction without excessive cracking and a "hotter" phase to maximise ammonia extraction. This retort consisted of an upper cast-iron section and a lower fire-clay section . It was supposed that the fire-clay would withstand the more intense heat, which cast iron would not have been able to do.

The retorts were grouped in fours, which shared one hopper and stood in two ovens, one on top of the other. A furnace suplied the heat for the bottom oven after which the products of combustion were expelled through chimneys. The upper section was heated partly by irradiated heat from below and partly by burning permanent gas to maintain the correct temperature. The discharging mechanism at the base was through a water-seal trough. The oil fumes and vapours were extracted midway up.[20]

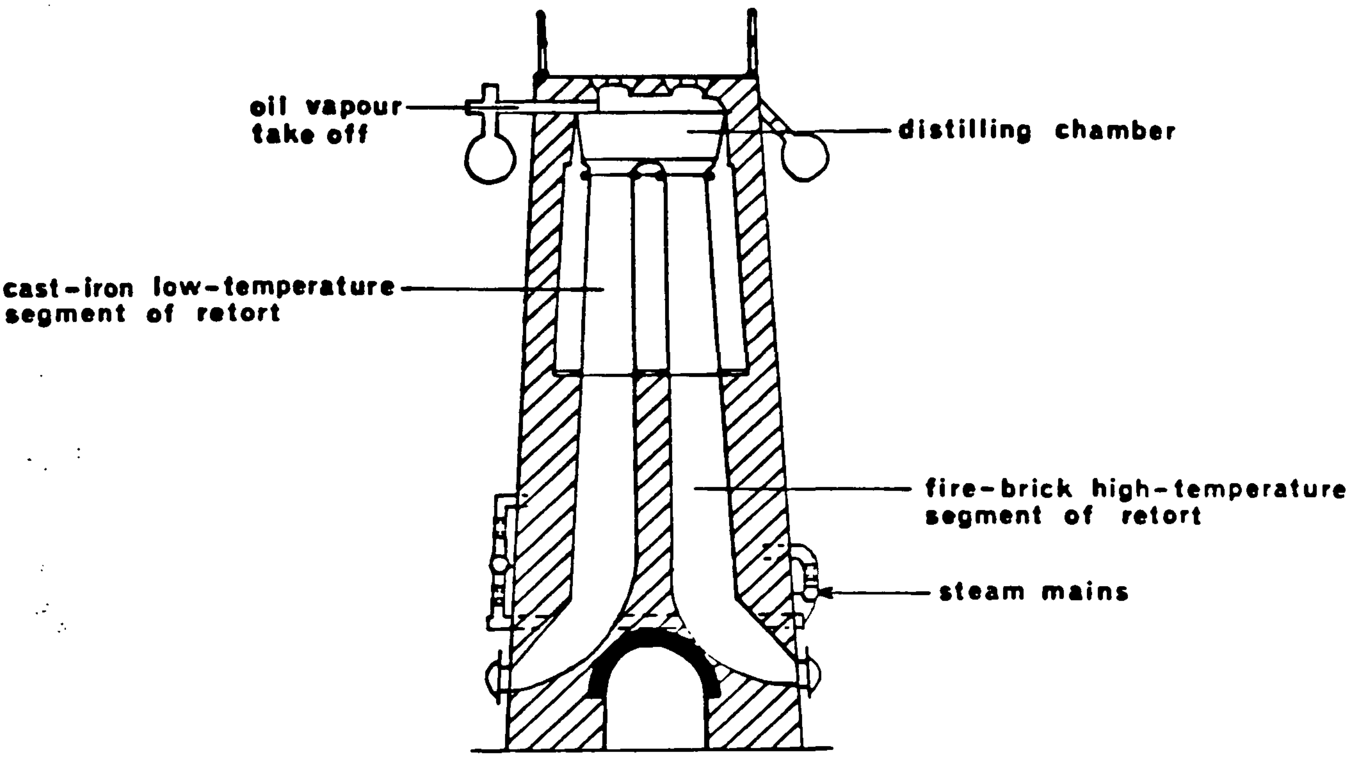
The retort yielded a similar volume of crude oil, but three times as much sulphate of ammonia as the Henderson retort (see section 4.3). It was operated at temperatures assessed by the appearance of the outer wall of the retorts: the cast iron section was maintained at "an insipient red heat", while the fire-clay portion was "at a bright red heat".[20]

Despite this very important conceptual advance, the Beilby retort was a commercial failure. The fire-clay portions cracked under the strain of temperature fluctuations, resulting in the explosive ignition of the contents of the retort. It fell into disuse in 1883.[20]

The Pentland Retort

In 1882 G.T. Beilby and William Young jointly patented a retort which embodied the concept of Beilby's two-stage retort, but which was more reliable and easier to operate. This design proved so successful that by 1897 three-fourths of the retorts in the Scottish industry were of this type.[26] Like Beilby's prototype, it also had an upper section of cast-iron, but the lower section was of fire-brick which was fully capable of withstanding the high temperatures required to extract ammonia. The most notable feature of the retort was its very efficient usage of heat energy.

The design was considerably more elaborate than that of previous retorts, a feature made necessary by considerations of heat economy. Redwood[20] is again relied upon for his detailed description of its design and operation. The structure consisted of sixteen shale-retorts combined with a single, vertical coal-retort. The shale retorts (Fig. 4.4) were in groups of four, sharing a common hopper and distillation chamber at the top. It was claimed by the inventors that the distillation chamber would obviate the first, crude-oil distillation in the refinery process, but, according to Redwood, this idea was spurious. The sixteen shale-retorts all rested in two ovens,one on either side of the coal retort. The combustion of permanent gas, derived from the shale retorts, was the main source of heat. The coal retort fulfilled two functions: first, by retorting the coal i.e. distilling the fumes, the ammonia locked up in the coal could be won, a process maximised by the injection of superheated steam; secondly, after condensation of the ammoniacal steam, the hot gases were passed through the pigeon-holed brickwork of the ovens, where they were burnt to supply additional heat for the shale retorts, coal retorts and steam superheater.



PENTLAND RETORT

Figure 4.4

The operation of the retort was, in principle, similar to that of the Beilby retort. The earlier models had a joint between the iron and brick sections, which became distorted if the retorts were allowed to cool. Thus, for the first time in this industry, it became necessary to operate the retorts continuously throughout the week, including Saturdays and Sundays. The retorts were charged every six hours; residence time was 18 hours and 28 cwt of shale could be retorted in 24 hours. Prolonged exposure to the moderate heat of the upper section effectively extracted as much of the oil distillate (without cracking) as reasonably possible. After this, in the lower section, maximal nitrogen extraction was attained at the highest temperature practicable. This upper limit was set by the fusion temperature of shale, i.e. ± 750°C. Steam injection was applied as in previous retorts. The discharging mechanism was rather crude, requiring a side-door to be opened to let spent shale drop into hutches alongside. Under steady working conditions the retorts lasted 6-7 years. Later models of the Pentland retort (1890's) were built entirely of brick, with a round cross-section at the top of 24 inches widening to 36 inches at the bottom, standing 50 feet high. It was found, however, that the brickwork tended to crack.[23]

Despite the fact that they did not burn spent shale, their cost of running was said to compare favourably with that of the Henderson retorts. The yield of crude oil was slightly greater in the Henderson retort, but the Pentland produced about four times as much sulphate of ammonia. Considering that the market price of this product was £22 per ton in 1880[9], this was an important financial advantage. Another commodity in high demand at the time, crude scale, was also produced more abundantly by the Pentland retort than by its predecessors.

The Pentland retorts were very popular, as is reflected in the following figures of the numbers of each design in use in Scotland in April 1897: Henderson: 896; Young and Beilby (Pentland): 3636; Others: 396.

The Pumpherston, Broxburn, Philpstoun and Young's retorts

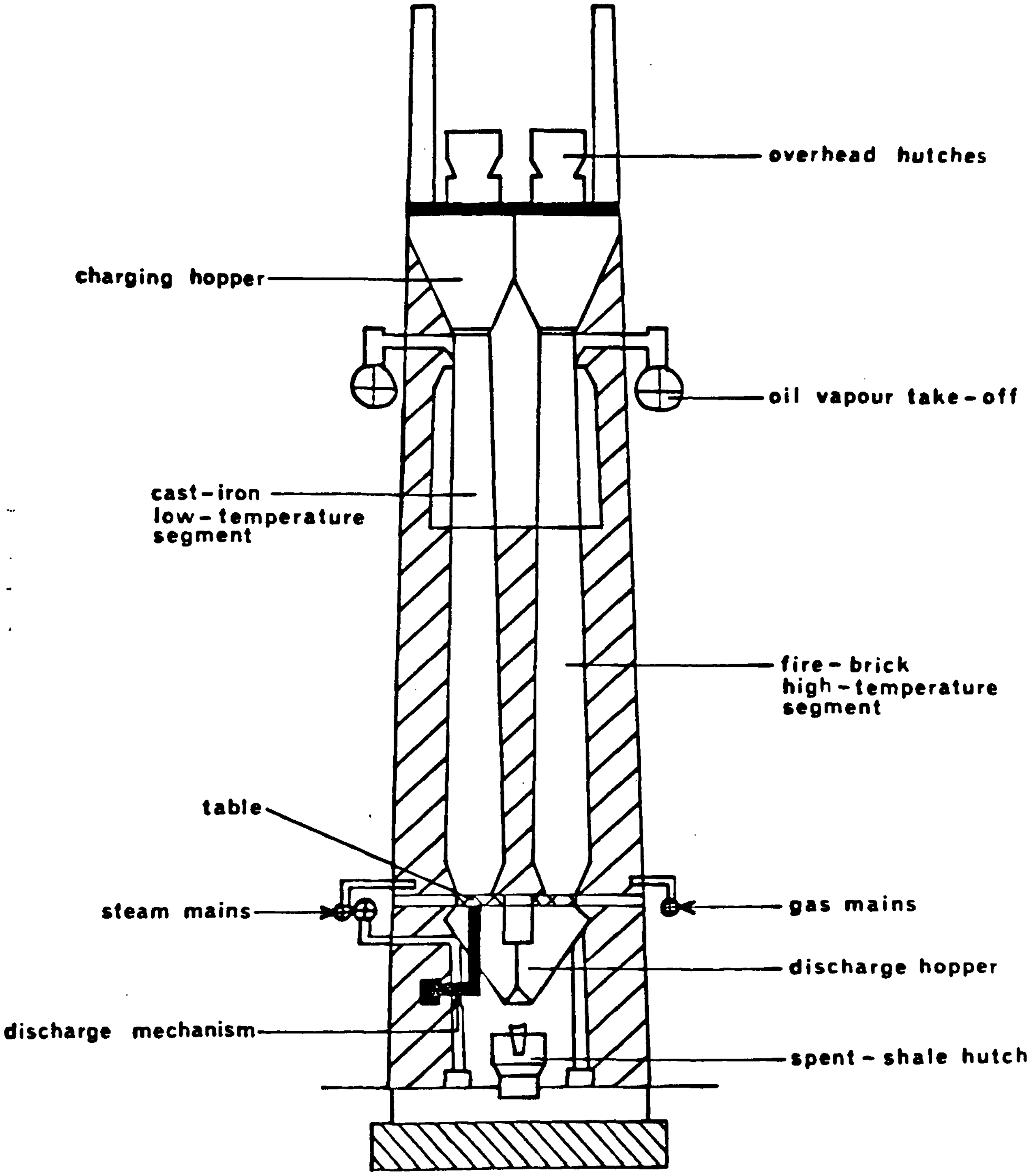
During the period 1895-1905 retorts were improved only in minor details of design and operation to make them more profitable; Stewart and Forbes[22] listed these advances as follows:

1. Continuity of operation by the introduction of mechanical discharge mechanisms;
2. increased length of retorts;
3. increased throughput of shale;
4. economy of fuel consumption;
5. reduction in labour costs.

The Pumpherston retort (also known as the Bryson retort)

This was patented by Bryson, Jones and Fraser in 1894 and underwent extensive trials (reported in the J.Soc.Chem Ind. in 1897 by Bryson) before being erected on a wide scale as one of the most efficient retorts of its time. By 1910 there were 1528 in use in Scotland. They were also used in other countries.

It consisted of a metal upper portion, 11'6" or 15'0" in length, resting on a firebrick portion which was 18'7" in height. The metal portion was circular and had a diameter of 2'0" at the top and 2'4" at the bottom, while the firebrick portion measured 3'0" at its base. (See Fig 4.5). The retorts were set in groups of four, but each individual retort had a separate flue system in the brickwork section; permanent shale gas was injected at the base of this flue system. From the top of the brickwork flues, hot gases



PUMPHERSTON RETORT

Figure 4.5

entered a common open chamber, the oven in which the metal retorts were set. Raw shale was dropped from overhead hutches that filled a large hopper which continuously fed the retort. The discharge mechanism consisted of a rotating curved arm which swept over a circular cast iron plate which supported the column of shale, causing the shale to drop into cast iron hoppers.[22]

The retort had a 15 ton capacity, including the hoppers which held four tons. The residence time was 24 hours and 70 cwt of raw shale was retorted in that time. The retort was started up by heating it with coal, but thereafter permanent gas from the process, supplemented by producer gas burnt in the flue-system, supplied all the fuel required. The internal temperatures were 350 - 480°C at the top and 650 - 700° at the bottom.[27] Thus the shale industry was rendered relatively independent of the coal industry. Superheated steam, a surplus from the boilers elsewhere in the plant, was injected at the base of the retort to maximise the extraction of nitrogen in the form of ammonia water. Usually, the steam equivalent of 1000lb of water was injected for every ton of shale.

This design was novel in several respects.[28] (a) It was much taller than its predecessors, thus prolonging the residence time without reducing the throughput; (b) it was remarkably heat-efficient, so that it required no fuel besides the permanent gas produced by the shale retorting process itself; (c) it had a wide, circular diameter which, up until that time, had been regarded as too great for heat to penetrate to the centre; (d) it was discharged continuously by mechanical means, thus preventing the notorious difficulty of shale fusion and blockage; (e) great care had been taken in the design of efficient charging and discharging mechanisms, thereby reducing labour costs.

The Pumpherston retort was almost half as costly to run as the Pentland retort (12d per ton compared to 22d per ton), yet yielded more products, worth an extra 12d per ton. (See section 4.3). Because of its strong structural design, the retort had a lifespan which was three to four times that of its predecessors.[22]

The Broxburn retort

This was patented in 1889 (Patent No. 6726) by N.M. Henderson who was then employed at Broxburn Oil Company. When the advantages of the Pentland retort became plain, Henderson set about designing a retort which was based on the Pentland, but which met some of its deficiencies. A detailed description of the retort was published in 1897.[21]

It also had an increased length, the upper cast-iron section being 14'0" and the firebrick portion 20'0". In cross-section it was rectangular; the metal section widened from 2'9½" by 1'2$^3/_8$ by 1'5" at the top, while the firebrick section had the dimensions 4'8" by 1'10" at the bottom[22]. A new type of "V" inter-locking brick was employed in its construction, thereby ensuring a longer retort life. The retorts were built in groups of four, but each retort had its own flue system. A large hopper at the top reduced manual labour and a constantly rotating toothed roller discharged the retort continuously. For heating it required coal producer gas as well as permanent shale gas, and these gases were introduced at the base of the oven in which each retort stood. The temperature in the metal section was 900°F (internal) and in the firebrick section 1300°F. The capacity was 100cuft, i.e. capable of holding 3.2 tons of crushed Broxburn shale. The residence time was 42½ hours. A bench of 88 retorts could put 160 tons of shale through in 24 hours[20]. It would appear that later the throughput rate was increased to 3.3 to 3.6 tons per day[22]. The equivalent of 120 gal water (per ton of shale) was injected as superheated steam.

The retort was noted for its reliability and durability and remained in use until about 1940.

The Philpstoun retort

This retort was patented by A.H.Crichton and was based on the Pentland retort. It did not attain widespread application, but remained in use at Philpstoun until the works closed down in 1931. It had an iron section of 10ft long on top of an 18'3" brickwork section. Like the Pentland retort, a coal retort was set in the middle of each bench, with eight shale retorts on each side. In later models the coal retort was built alongside the bench of the shale retorts, since the coal retorts required more frequent maintenance work. Gas from the coal retorts distilled downwards and was then fed into the flue system surrounding the shale retorts, in a zig-zag pattern. The discharge mechanism was a manually-operated system of levers which emptied into a hopper. The retort was partially discharged every 6 hours.[29] The throughput was said to be similar to that of the Young and Beilby retort.

Young's retort (the Young and Fyfe retort)

This retort was introduced about 1913 and still being used in 1938. It was based on the principles of the Pentland retort and had a metal section of 14'0" and a firebrick section of 20'0" in length. It was rectangular in cross-section with the metal portion measuring 2'9½ by 1'2$^3/_8$" at the top, and 3'0" by 1'5" at the bottom. The firebrick section measured 4'8" by 1'10". Unlike the Pumpherston and Broxburn retorts, which had separate flue systems for each retort, Young's design had flue systems shared by more than one retort. The retorts were placed eight retorts to a setting. Charging was done through a large hopper, while discharging was through side doors.[22] Steam, equivalent to 120 gallons of water per ton was injected. The throughput was 3.3 to 3.6 tons per day and the residence time approximately 24 hours.[22]

Air Injection (Pumpherston,Broxburn & Youngs retorts after 1937)

Stewart and Forbes, in reviewing the status of the industry at a conference in 1938[22] made mention of a series of experiments conducted in 1937 and 1938 which showed that air injection at the base of the retort more than doubled the throughput potential of existing retorts[11]. In essence, the combustion of the residual carbon in the "spent shale" greatly increased the available heat in the lower segment of the retort. Experiments showed that, provided a commensurate increase in steam was injected, the oil yield was unaltered, while slightly less ammonia was obtained per ton of shale. (see section 4.2.5) Since the heat was generated internally, the life of the retort was not shortened, nor were there any additional fuel costs.

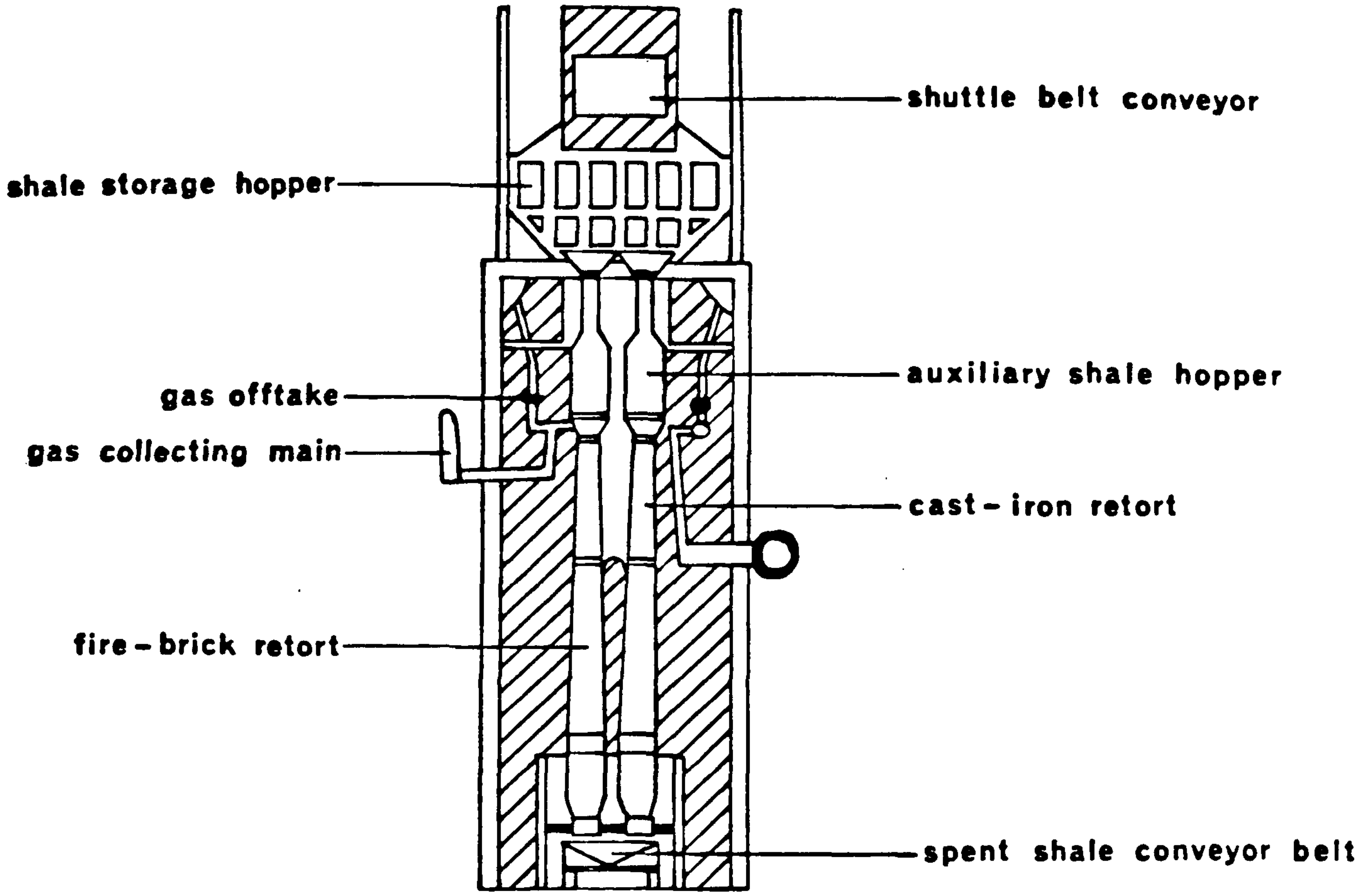
The introduction of air injection was therefore an advance of great economic significance. By 1938 almost all of the three principal retorts in use (Pumpherston, Broxburn and Young's retorts) had been converted and were working at a throughput of 10 tons per day.

The Westwood retorts

The demands for increased production and greater economy engendered by World War II called for drastic rationalisation of retort works and it was therefore decided to centralize retorting. Thus the Westwood works was constructed during 1939-1941; it had a retorting capability of 1200 tons per day[11].

Two benches were built, each having fifty-two retorts and individual retorts were grouped in sets of four. In design, these retorts resembled the Broxburn retort. The metal section was 14ft long and the firebrick section 20ft[8] (See Fig 4.6). The metal part was oval in cross-section, with dimensions of 2'9½" by 1'2$^{3}/_{8}$" at the top and 3'6" by 1'5" at the bottom. The firebrick segment was rectangular in cross-section, measuring 4'8" by 1'10". It had large main-storage charging hoppers, each serving four retorts; these were discharged, by means of hand-operated levers, into a smaller (2 ton capacity) auxilliary hopper above each individual retort. The latter was also manually discharged into the retort and were fitted with cast-iron, dished, sliding-doors which were air tight against the retorts' operating suction of 7 inches w.g. The oil fumes were extracted from the top of the retort, directly below the auxilliary hopper. The cast-iron section rested on the fire-brick section which, in turn, rested on a seating of ironwork, consisting of an extractor, spent-shale hopper and water-sealed discharge door. The extractor was a screw-device, consisting of cast-iron stars mounted on a rotating square shaft so that the teeth of the stars formed a helix. The extractor dropped the shale, at a fixed rate, into the discharge hopper below it. Here water was sprayed onto the hot shale to reduce its temperature to 150°F. The spent-shale hopper had a water-sealed door, so that the vacuum in the retort could be maintained.

Each retort was heated individually. The heating gases entered at the bottom and, through a system of flues, passed five times backwards and forwards along the side of the retort before reaching the top of the firebrick section. Heating was controlled by admitting air at various heights.



WESTWOOD RETORT

Figure 4.6

The metal sections were heated in pairs by waste gas passing up from the flues of the brick section. The (internal) temperatures in the metal section ranged from 400°F at the top to 1075°F at the bottom; in the brick section the range was 1150°F to 1450°F near the bottom. These temperatures were, in summary, attained by:

1. external heating by the burning of permanent shale gas,
2. internal heating by the injection of superheated steam,
3. internal heating by the combustion of residual carbon in the spent shale as the result of air injection.

Of the steam used for injection, 37% was obtained from the exhaust of the plant's turbo-generator. Air was mixed with the steam in a critical proportion and this was regulated by recording flow meters.

Efforts were made to conserve energy and one important contribution was made by the system of waste-heat boilers which extracted the heat from the smoke of the heating-flue system and supplied 63% of the steam requirements of the retort. One such boiler was active for each bench of retorts and, at a throughput of 1200 tons shale per day, each produced 8000lb/hour of steam at 120 p.s.i. The temperature of the waste gas entering the boilers was 1000°F and 420-460°F upon leaving.

Three gas producers, each designed to produce 124000 cu.ft/hr of 145 BTU gas from 15 cwt/hr of anthracite beans, were used to supply producer gas to start up the retorts. After a throughput of 8 tons shale per day per retort was achieved, more than sufficient permanent shale gas was generated and the producers were shut down after December 1941.

The spent shale was discharged from the spent-shale hoppers onto a conveyor belt by means of a travelling shute which served the entire bench of 52 retorts. The shale was then carried to a despatch happer which emptied, by remote control, into 6-ton self-tipping buckets which deposited the shale on waste bings. These buckets ran on rails, being hauled by three electrically driven 160 h.p. M-V reversible motors through gearing to the rope drums. One haulage man per shift handled the entire spent-shale operation. Maintenance of the rails etc., was provided by eight men who were always on day shift.[11]

The throughput was, on average, 12 tons of shale per retort per day. The crude oil and crude spirit was approximately of the same quality as that obtained with the Pumpherston retort.[11] In ca.1950 the throughput was increased to 14 tons per day, and according to Smith and Balloch[11], the yields remained the same and the air and steam requirements were unaltered. Only an increased suction in the retort-vapour mains was necessary. These retorts remained in operation until the industry was closed down in 1962.

4.2.3 Retort temperatures

The retorting temperature of horizontal retorts is not on record and was, evidently, entirely a matter of judgement for the coal-furnaceman.[20]

According to Redwood[20] the introduction of steam into the early vertical retorts (eg Kirk's retort) reduced the risk of marked temperature variations. Factors that influenced the temperature in the coal-fired (early) vertical retort temperatures were: the intensity of the coal fire; the rate of emptying of the retort; the volume of steam injected per ton of shale and the temperature of the steam; the size of the orifice of the flue leading to the chimney stack. All these factors could be controlled by the retortman.

The temperatures of the Pentland retort (patented 1882) were judged according to the glow of the retort itself: the upper part (cast iron) portion was heated to a "low, black heat" whereas the lower portion of fire-brick was heated to a "bright red heat". Again, no measurements are on record, and Kennaway[26] quoted Mr E.M. Bailey (Chief Chemist of the Pumpherston Works) as having said that "it is evident from the lively description of Beilby that these retorts were very strongly heated, but no exact temperature can be stated". Cadell in 1813 quoted temperatures of 1100°F and 1800°F respectively for the upper and lower portions of retorts;[24] he was probably referring to Henderson's retort (later model, patented 1889).

Measurements of temperatures in retorts made ca.1923 indicated that shale was exposed to a temperature of 510°C for 17 hours, 510-704° for 8.5 hours and 704° for 4.5 hours.[26] The latter temperature could not be exceeded, since fusion of the shale particles would occur.

The Pumpherston retort (patented 1894) was operated at temperatures of 350-480°C in the upper section and 650-700°C in the lower section. Heat was applied externaly (before 1938 when air injection was introduced, so that a maximum external temperature of 1000°C was attained in the retort furnace.[27]

The Westwood retorts were operated at the following internal temperatures:

	Cast iron section	Firebrick section
Top	400°F	1150°F
Bottom	1075°F	1450°F

4.2.4 Steam injection

The injection of steam into the lower (hottest) section of vertical retorts was first introduced in 1860.[24] Steam was seldom, if ever, used in horizontal retorts.

The steam was thought to contribute to the retorting process in five ways:[22]

a) at the high temperatures prevailing at the base of the retort (ca 1400°F) the steam was dissociated into hydrogen and oxygen. The hydrogen combined with nitrogen in the oil-free shale at the base of the retort, to form ammonia.

b) it reacted with the residual carbon in the oil-free shale to produce combustible gas. This reaction also took place in the high-temperature segment of the retort. Although usually denoted "water-gas", it was not true water-gas, as it contained up to 20% CO_2. Without steam introduction, approximately 1250cu.ft of gas was obtained per ton of shale; this volume could be increased to 13000-14000 cu.ft with steam injection. Thus the free carbon content of "spent-shale" was reduced from 5% to 3% or less by steam injection.

c) it contributed to the even distribution of heat throughout the retort.

d) it had the effect of sweeping the oil vapours away from the excessively hot areas of the retort as soon as they were formed, thus reducing cracking of long oil molecules within the retort.

e) it cooled the extraction mechanism and the spent shale in the lowest part of the retort.

In the retorts in use in 1938, low-pressure steam was generally used.[22] This was mainly collected from the exhausts of various processes and power units throughout the facility. The steam-equivalent of 120 gallons of water per ton of raw shale was injected and this resulted in a yield of ca. 90 gallons of ammonia liquor.

The Westwood retorts (after 1941) required 900lb of steam per ton of shale. Four water-tube coal-burning boilers were installed to supply steam for the nearby pit-winding as well as the retorts. Sixty-three percent of the steam required for retorting was generated in the retort itself; the remaining 37% was derived from the aforementioned boilers and the sulphate-of-ammonia plant.[11]

4.2.5 Air injection

The greatly increased throughput potential brought about by the injection of atmospheric air into the base of existing retort designs in 1937-1938 has been alluded to previously.

The first recorded experiments with air injection[23] were by Young and Beilby, who attempted to burn the residual carbon in the spent shale at the base of their Pentland retort. In 1882 they added air to the injected steam, but found that, although combustion of the carbon in the shale was virtually complete, the required volume of air made condensation and scrubbing of the volatile oils too complicated.

In 1884-85 an attempt was made, in the "Couper-Rae retort" to separate the ammonia in the lower retort entirely by the agency of internal heat generated by air injection. However, the process failed because these retorts had other design faults.[30] Later experiments with air injection (circa 1890) by A. Neilson and A.C. Thomson, using a retort built like a blast furnace met with limited success. It only worked with shales possessing a large percentage of fixed carbon.

Air injection technology received no further attention in Scotland until a series of experiments was conducted at the Pumpherston facility in 1937.[22] Methods were being investigated whereby the throughput of existing retorts could be increased without a loss of products yielded. Laboratory experiments indicated that the introduction of air with steam allowed a much higher temperature within the retort before fusion occurred. It was also shown that the air caused a much more rapid and complete combustion of the residual carbon in the spent shale at the base of the retort. By the injection of air, the throughput (using a standard Broxburn retort) could be increased from 4 tons to 12 tons per day. The only limiting factor was said to be the size of the vapour mains which could not take off the vapours at an even greater rate. Air was injected at a rate of ca. 5000cu.ft per ton of shale. Experiments showed that the oil and naphtha yields were maintained up to the maximum throughput, whilst the ammonia production declined with increasing throughput. The maximum loss of ammonia was, however, not regarded as being excessive: it fell from 31.68 lb/ton at 4 tons per 24 hours to 23.22 lb/ton at 12 tons per 24 hours throughput. Clearly, the commercial advantage of air injection was very significant indeed, and the practice was rapidly extended throughout the industry. The Westwood retorts, working at an average throughput of 12.2 tons per 24 hours were operated with air injection at a rate of 4,450 cu.ft per ton and steam injection of 900lb per ton.[11]

4.3 Yields and products

The yield of the various products derived from shale in the retorting process depends not only on the retort process, but also on the specific type of shale being used. It follows that no absolute statements regarding the properties of any particular retort can be made and in this section reference will only be made to experiments in which successive generations of retorts were compared.

The introduction of the vertical retort led to some experimentation to compare the products yielded with the horizontal retorts then commonly in use. Redwood[20] reported some results comparing the performance of the Kirk vertical retort with the horizontal retort, using the same source of crude shale in both retorts.

	Retorts			
	Horizontal		Kirk's vertical retort	
Crude oil per ton of shale (gal)	34.2		39.7	
Specific gravity of crude oil	0.87		0.89	
Finished Products	Gals.	% of crude by Vol.	Gals.	% of crude by Vol.
Naphtha	0.86	2.5	0.36	1.0
Burning oil	15.9	46.5	14.83	40.5
Crude scale	1.95	5.7	3.8	8.5
Lubricating oil	3.46	10.1	3.82	10.4

Note that, with regard to the finished products, horizontal retort "crude" was compared with the vertical retort "once run" oil. The vertical retort crude required an initial distillation before acid and soda treatments; this process was unnecessary when the crude oil was produced in a horizontal retort. The increased production of crude scale in the Kirk retort was a significant financial advantage.

Henderson's retort of 1873 made use of the combustion of the residual carbon in spent shale, without sacrificing the quality or quantity of yield. Redwood[20] reported the following yields, comparing an "old vertical" retort (presumably Kirk's retort) and Henderson's retort:

	Retorts	
	Old vertical	Henderson's
Crude oil per ton of shale (gal)	22.5	22.5
Ammonium sulphate (lbs)	19.6	10.3
Finished Products (% of crude by vol.)		
Naphtha	Nil	1.5
Burning oil	41.5	44.4
Intermediate oil	4.6	1.6
Crude scale	11.6	13.0
Lubricating oil	16.7	17.1
Total yield	74.4	77.6

Thus, the Henderson retort produced a crude oil capable of yielding a higher percentage of marketable finished products than its predecessors. The lower yield of ammonia was, however, soon recognised as being a serious disadvantage. Beilby's two-phase retort aimed at the maximum extraction of ammonium by heating the lower section of the retort to much greater temperatures. Redwood[20] provides the following statistics, comparing "old vertical retorts" (presumably Kirk's retort) with Henderson's and Beilby's retorts.

	Old vertical	Henderson's	Beilby
Crude oil (per ton)	23.49 gal	23.27 gal	21.05gal
Sulphate of ammonia (per ton)	20.97 lbs	11.57 lbs	30.36lbs
Finished products (% of crude by vol.)			
Naphtha	5.0	5.0	2.0
Burning oil	33.3	36.83	33.86
Intermediate oil	6.00	3.00	5.00
Crude scale	9.26	10.48	12.94
Lubricating oil	15.40	17.26	17.36
Total per cent	68.96	72.57	71.16

Thus the Beilby retort offered the dual advantage in higher yields of both ammonium sulphate and crude scale, without a loss in production of the still-lucrative burning oil.

The Pentland retort, designed by Young and Beilby improved on the basic concept of Beilby's retort and was reported by Redwood[20] as yielding the following products in comparison with the Henderson retort:

	Henderson	Pentland
Crude oil (per ton)	34.18 gal	30.20 gal
Sulphate of ammonia (per ton)	12.34 lbs	44.76 lbs
Finished products (% of crude by vol.)		
Naphtha	2.0	0.75
Burning oil	41.08	34.27
Intermediate oil	1.02	4.5
Crude scale	10.87	13.57
Lubricating oil	17.36	20.55
Total	73.05	73.64

These figures suggest that there was some reduction in the yield of burning oil derived from the crude oil extracted in the Pentland retort; this might have been due, in part, to cracking due to the higher temperature at the base of this retort. The increased yield of ammonia took advantage of the favourable market price of this commodity at the time. Experiments which were done in 1895 compared the performance of the Pentland retort with that of the Pumpherston retort. Pumpherston shale was used and the tests were made simultaneously.

	Pentland	Pumpherston
Throughput of shale per day	1.5 ton	3.9 ton
Crude oil (per ton)	12.48 gal	11.86 gal
Specific gravity	0.868	0.8665
Setting point	81°F	76°F
Sulphate of ammonia (per ton)	47.94 lb	46.69 lb
Yield of refined products	77.35 %	79.34 %
Yield of refined wax	11.06 %	11.31 %

The retort designed by N.M. Henderson in 1897 (Patent 6726) which was generally adopted by the Broxburn works gave significantly better yields than the previously patented Henderson retort (Patent 1327 of 1873). The new model gave 3 gals more crude oil than its predecessor and the yield of sulphate of ammonia was increased from 16-17 to 43lb per ton.

A comparison between the yields of the Pumpherston retort and Henderson's Broxburn retort was made in 1902 using Dunnet shale and the results are shown below.

	Pumpherston	Broxburn
Crude oil (per ton)	32.5 gal	33.08 gals
Specific gravity	0.8775	0.878
Setting point	93°F	99°F
Sulphate of ammonia (per ton)	34.93 lb	33.48 lb

Refined products (% of crude)	%	Spec.Grav	%	Spec.Grav
Naphtha	1.77	0.751	3.55	0.751
Burning oil	25.10	0.801	26.02	0.802
0.835 oil	0.42	0.835	0.30	0.836
Gas oil	10.38	0.848	9.87	0.849
Cleaning oil	7.62	0.873	6.93	0.876
Lubricating oil	9.23	0.891	9.17	0.890
Crude solid paraffin	15.18	MP115.8°F	13.671	MP116.2°F
Residuum	3.00		2.96	

The reporter of these results, E.M. Bailey,[10] emphasised that it was possible "to obtain very different results from the same retort using the same shale, if the conditions of heating were varied".

In reporting the results of the experiments (conducted in 1937-38) with air injection, Stewart and Forbes[2] found that the oil and naphtha yields were maintained despite the adoption of increased rates of throughput of shale.

RESULTS OF EXPERIMENTS WITH AIR INJECTION (STEWART & FORBES)[22]

Throughput	Oil yield	Naptha	Ammonia	Air injection
4 tons per day	21.1 gal	2.91 gal	31.54lbs	0
12 tons per day	20.95 gal	3.23 gal	23.22lbs	6400cu.ft. per ton

The Westwood works came into full production in December 1941. After that date no other retort works were operated in Scotland. The following production figures at a throughput rate of 12 tons per retort per day were regarded as typical in 1950.[11]

YIELDS OF CRUDE PRODUCTS: WESTWOOD RETORTS

Shale throughput	12.2 tons/retort/day
Yields	
Crude oil	19.53 gal/ton
Crude naphtha	3.66 "
Total	23.19 "
Sulphate of ammonia	26.0 lb/ton
Permanent gas	9 500 cu.ft/ton
Air	4 450 cu.ft/ton
Steam	900 lb/ton

Note: The yield of oil is substantially 100 per cent of laboratory assay, but sulphate of ammonia is only 80 per cent of laboratory assay.

YIELDS OF REFINED PRODUCTS: WESTWOOD RETORTS

	Crude oil	Crude spirit
Sp.gr.at 60°F	0.88	0.74
Distillation:		
I.B.P. (°C)	169	50
2% dist. (°C)	-	64
5% "	200	72
10% "	218	79.5
20% "	253	8.5
30% "	287	96
40% "	317	105
50% "	340	114
60% "	-	124
70% "	-	137
80% "	-	152
90% "	-	174.5
F.B.P. "	-	249
Total distillate (%)	56.0	98.0
Residue (%)	44.0	1.0
Loss (%)	Nil	1.0
Lab, temperature, (°F)	68	64
Bar, pressure, (mm Hg)	761	755
Dist. at 70°C (%)	-	4.0
" 100 "	-	34.5
" 140 "	-	73.0
" 175 "	1.0	-
" 200 "	5.0	-
" 225 "	12.5	-
" 250 "	19.5	-
" 275 "	26.0	-
" 300 "	34.5	-
" 325 "	43.0	-
" 350 "	55.0	-
Sp.gr. of dist at 60°F	0.85	-
Sp.gr. of residue at 60°F	0.93	-
Sulphur (%)	0.39	0.21
Hard asphalt (%)	0.37	-
Carbon residue (%)	1.60	-
Congealing point (°F)	86	-
Viscosity, Red.I, 140°F (sec)	39	-
Ash (%)	0.0044	-
Wax content (methylene chloride at -40°C),%	12.13	-
Melting point of wax (°F)	123	-
Bromine number	-	66
Aromatics (%)	-	11

4.4 Crushers

Shale fragments brought up from the mines were too bulky to undergo retorting without prior crushing. They tended to congest the retorts and could not be heated evenly. During the early years of the industry, gangs of men using long-handled hammers were employed to break up Boghead coal and, subsequently, shale. This method of fragmenting shale was too labour intensive, and led to the invention of mechanical breakers.

The first mechanical breaker was constructed of heavy timber lined with iron plates and used toothed cast-iron discs as breakers.[20] Bailey,[10] in writing on the retorting of shale, referred to the crushers in use at the time as having "revolving heavy cast-iron rollers fitted with wedge-shaped blunt teeth made of especially tempered hard steel". A detailed description of the crushers in use at Westwood in 1950, was provided by Smith and Balloch,[11] who made mention of the fact that they were "of the design which has been in use in the Scottish shale industry for a lifetime". The rollers were of cast iron, 5ft long and 2ft10in in diameter; each roller had 336 steel teeth, with specially hardened points. The distance between the rollers was set at ½inch between opposing teeth.

The rollers were adjusted by packing plates. They revolved at 4½ rpm and were suprisingly impervious to wear: after crushing 1,500,000 tons of shale, the wear on the teeth was found to be ½ inch.

CHAPTER 5

DUST EXPOSURE ESTIMATES

5.1 Documentary evidence

During the lifetime of the industry in Scotland, the existence of shale workers' pneumoconiosis was not generally recognised and no systematic investigation of dust exposure levels was made to parallel the very active research that was being done in the coal industry in Britain.

In 1976, at the request of this Institute, the Chief Inspector of Mines carried out a search of the reports of Divisional Inspectors in respect of safety and health matters in the shale industry. He reported that

> "In the report of 1957 reference is made to the fact that the dust produced in shale mines contained very little free silica and the prevalence of damp conditions had a bearing on the small amount of dust produced.
>
> "In 1958 it was said that airborne dust was not prevalent at the mines."

A similar search was made of records held by the Health and Safety Executive (HSE) by Dr E.S. Blackadder, Senior Employment Medical Advisor (Scotland).[15] He was able to locate two chest radiographs which showed early pneumoconiosis; one man had been a shale miner for 40 years and the other for 41 years. Apart from these two films, no information was available to the HSE to suggest that pneumoconiosis occurred on a wide scale or that it had serious consequences among shale workers. Dr Blackadder consulted his predecessor, Dr Doig, who stressed that neither he nor any chest physician in West Lothian had knowledge of definite cases of pneumoconiosis among shale workers.

None of the references quoted made reference to dust measurements, relative dustiness of different work-sites or dust-related diseases, although several made mention of the fact that bath houses had been installed at Retort Works facilities to prevent skin cancer. Only two reports discussed the issue of dust-generation in retort works, as follows.

Stewart and Forbes in 1938 argued against the adoption of retort-designs which differed from the conventional Scottish vertical design on the grounds that they were disadvantaged by various factors including "dust generation"[2]. No further reference to dust conditions was made by these authors, but it would appear that mechanical stirring-devices and the like were eschewed partly because they produced dust, which complicated the distillation process. Smith et al [27], in a comprehensive chapter on Scottish Shale Oil in The Science of Petroleum, also emphasised the disadvantages of dust production in retorts with mechanical stirrers and stated that dust-generation was less troublesome in Scottish retorts.

Some interesting evidence was led in Arbitration Procedings in 1917, at which it was testified that retort chargers worked in particularly dusty conditions and that "You know a retortman's cough when you meet him on the street. He has a chest that is known in connection with his trade."[31] Regarding dust conditions in mines, most authors state that the shale mines were damp and that dust was not a problem. For example, Caldwell[9], in describing experiments to prove that shale-dust suppressed flame-propagation by coal dust, stated that "Shale-mine dust is invariably composed of shale and blaes mixed, but it is found in very few roadways, as the strata are usually damp or even wet." In his presentation on "Safety in Scottish Oil-Shale mines" at the 1938 Conference, Winstanley discussed firedamp (methane), the fumes generated by gunpowder and a variety of other hazards, but no mention was made of shale dust.[14] At the same Conference, Sneddon, Caldwell and Stein discussed the ventilation arrangements in mines and stated, "What has weighted mostly in oil-shale mines has been the speedy removal of gunpowder fumes from the amount of blasting necessary...."[4]

In evidence led at a Shale Miners Arbitration (1903-1904)[32], the miners' representative argued that "A good many mines have steep gradients, so steep that when they fire these shots it is utterly impossible to ventilate them and the result is the miners are working a whole day in heavy smoke" (page 41, Wilson's argument). Again, no mention was made to indicate that shale-dust was a recognised problem in the mines.

5.2 Personal interviews

Personal interviews with ex-shale workers were conducted in two phases. The first series of interviews was conducted in September/October 1982, when the research team was making local visits in the shale villages in order to trace surviving members of the Provident Fund. During this time a number of men were identified who appeared to be particularly knowledgable about one or other aspect of the industry and notes of their statements were made. The second series of interviews was conducted during August/September 1983, at which time the history of the industry was being researched. The author used the occupational histories from the Provident Fund forms as a guide to identify men who worked in various parts of the industry at various times. Most of these latter interviews were conducted by telephone. These interviews were structured in so far that each man was asked to comment only on those aspects of the industry of which he had first-hand knowledge. In this regard the author was impressed by the fact that most men were careful to avoid making generalisations or speculations. The men's memories were tested by asking them questions (e.g. important dates in the industry or the number of retorts at the plant where they worked) the answers to which were known to the author. In all instances care was taken to corroborate statements by questioning several informants.

5.3 Conclusions

The interviews led the author to accept the following generalisations regarding the presence of visible dust and oil fume exposure in the industry:

Retort Works

1. The crushers generated a great amount of dust.
2. Working at the retort tops exposed the men to moderate amounts of dust and fumes.
3. Working at the bottom of retorts exposed men to lower amounts of dust than at the top.
4. Working at the top of bings exposed men to great amounts of spent shale dust.
5. Working around the retorts entailed a low degree of dust and fume exposure.
6. During the past 80 years, progressive mechanisation and the adoption of remote-control devices tended to reduce men's exposure to dust and fumes.

Mines

1. Most miners commented that shale mines were not dusty.
2. Most miners described the gunpowder fumes as having been the most troublesome aspect of shale-mining at the face.
3. During the past 80 years the degree of dust exposure remained substantially unaltered since the room and pillar method remained the most widely used technique and machines that generated dust were not used to any significant extent.

CHAPTER 6

MINERALOGICAL CHARACTERISATION OF SCOTTISH AND GREEN RIVER FORMATION OIL SHALES

6.1 Introduction

A general impression of the importance of the Scottish oil shale experience to the assessment of risks involved in the development of the industry in the United States at least as far as lung disease is concerned may be gained from a detailed comparison of the geology and mineralogy of the shales of both areas. This section of the report is a summary of the geological background and mineralogy from both published data and from analyses carried out at IOM.

6.2 Geology of oil shales

6.2.1 Scottish Shales

The oil-shale succession of the Lothian Region outcrops over an area of about 150 km^2 west and south-west of Edinburgh (Figure 6.1). Details of the general geology, the stratigraphy and of the occurrence of the oil-shale seams are well described[1]. The whole sequence, with seams identified, is shown in Figure 6.2. To summarise, the oil-shales occur in the Upper Oil-Shale Group and the upper part of the Lower Oil-Shale Group of the Lower Carboniferous strata. Typically, the oil-shales are fissile, finely laminated, fine-grained, tough and sometimes flexible rocks, usually dark brown or black in colour but a rich ochreous brown when finely powdered. The oil-shale seams are interbedded within about 1,000 metres of less bituminous shales, mudstones, marls and sandstones with occasional thin shell beds of marine origin and volcanic tuffs.

FIGURE 6.1 Map of the Lothians showing the outcrop of the Oil-Shales and the sample collection localities (1 - 11) as described in the text. (After Cameron and MacAdam, 1978)

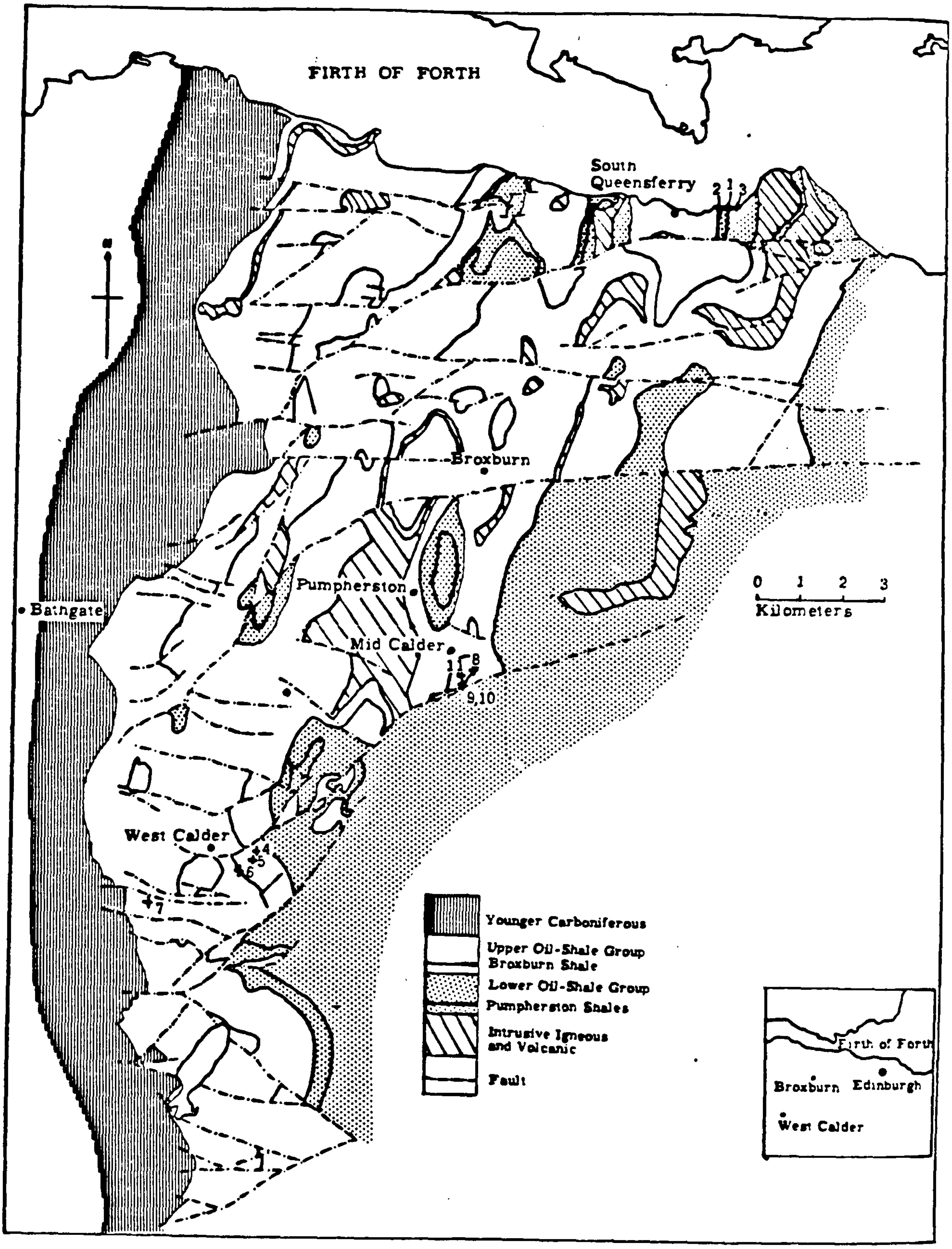
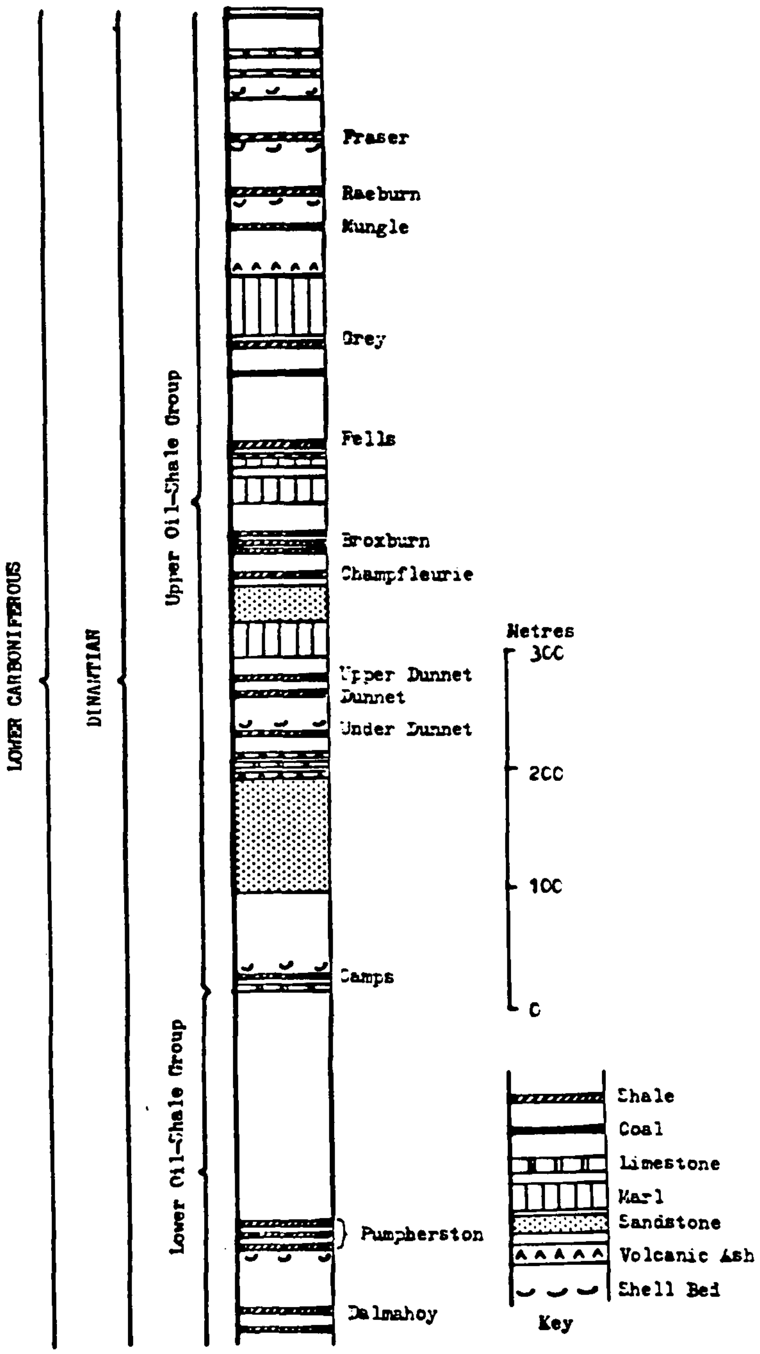


FIGURE 6.2 General geological succession of the Oil-Shales of the Lothians. (After Cameron and MacAdam, 1978).



The oil-shale seams grade almost imperceptibly into less bituminous shales and oil-rich seams are consequently difficult to distinguish. They are inconsistent in thickness throughout the area so that workable seams in one district may be thin or absent in others. About fifteen seams with thicknesses from 1.2 - 3.3 metres are known, of which about eleven were exploited between 1870 and 1962. The majority of the mines worked individual seams, especially in the case of the more isolated seams in the upper part of the succession, but a proportion of the mines worked two or more seams at different levels. The Broxburn and Pumpherston Shales are unusual in that these names refer to groups of closely spaced seams which are variable in number and thickness throughout the area but which were worked as groups in the same mines.

An impression of the relative economic importance of the seams is given in Table 6.1, which shows the number of mines at which particular seams were exploited and the total area of the workings (hectares). The Table gives no indication of the extent of the individual workings, but it is clear nevertheless that the Broxburn, Fells and Dunnet Shales were very important in the pre-1920 history of the area while the Broxburn and Dunnet Shales continued in importance until the closure of the industry. The Pumpherston shales and others were locally or temporally important in the sense that small numbers of mines produced relatively large amounts of shale.

TABLE 6.1

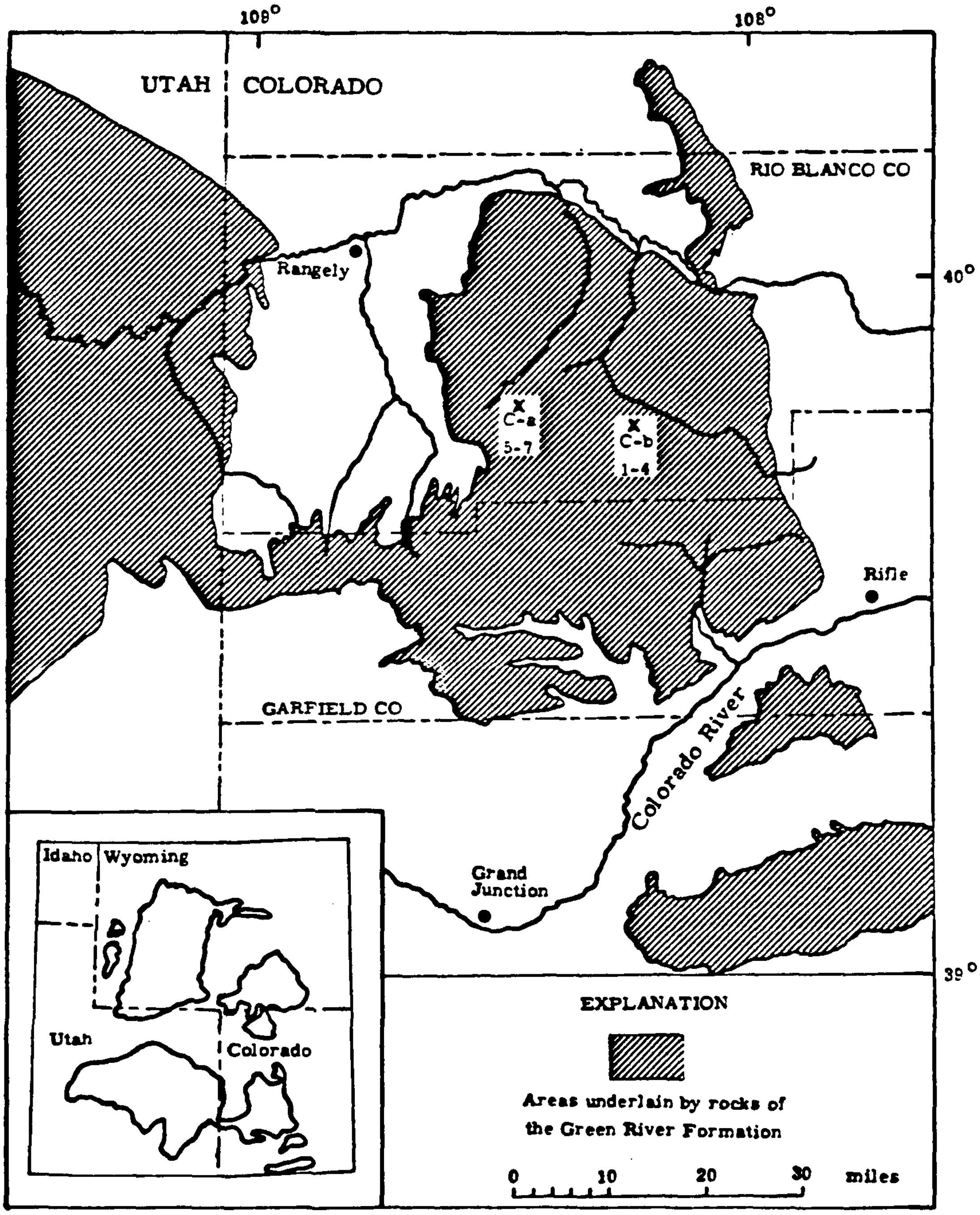
Scottish industry : the number of mines working particular seams and total area worked, grouped according to date of closure.

Seam Worked	Pre 1920	1920-29	1930-39	1940-62	Total	Total Area Worked (Hectares)[1]
Fraser Shale	2	1	-	1	4	118
Raeburn Shale	2	1	-	-	3	9
Grey Shale	-	1	-	-	1	-
Fells Shale	20	4	2	1	27	787
Broxburn Shale	40	7	3	9	59	1548
Champfleurie Shale	-	-	1	-	1	52
Upper Dunnet Shale	3	2	1	-	6	28
Dunnet Shale	15	4	3	12	34	983
Under Dunnet Shale	2	1	1	5	9	87.5
Camps Shale	-	1	3	-	4	491
Pumpherston Shale	3	1	2	2	8	584

6.2.2 United States Shales

The American oil-shales upon which most commercial interest has been concentrated are those of the Green River Formation of Colorado, Wyoming and Utah (Figure 6.3). This is a very thick sequence (2,100 m) of lower and middle Eocene rocks (50 million years old) extending over 41,000 km^2 in four depositional basins of which the one with the thickest and richest oil reserves is the Piceance Creek basin of Colorado. This basin extends over 5,180 km^2 in Garfield and Rio Blanco Counties, North of the Colorado River near Grand Junction. Economically the most important part of the geological sequence in this area is the Parachute Creek Member. Within this, the Mahogany Zone, the top 50 m, contains rock with the highest yields of oil including one exceptionally

FIGURE 6.3 Map of the Piceance Creek Basin, Colorado, showing the outcrop of rocks of the Green River Formation and the localities of the samples (1 - 7) as described in the text.



oil-rich layer, the Mahogany Band (Figure 6.4). The lower zones have relatively oil-rich and poor shale throughout the sequence.

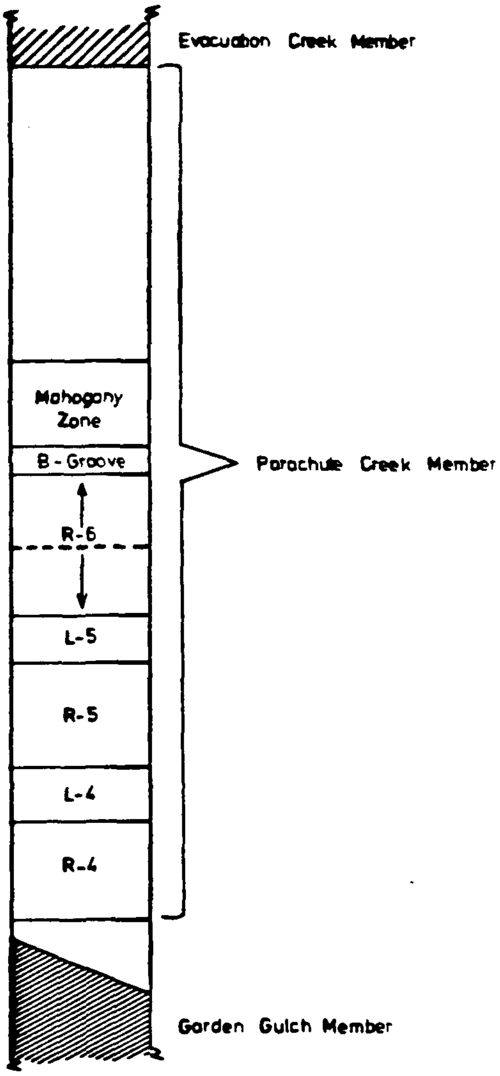
While the rocks in the US deposits have been referred to as shales, the predominant rock type should more properly be called marl, a non-fissile carbonate rich mudstone, but for the purpose of this report, the term shale will be used. The shales are tough thinly bedded fine grained rocks which are dark brown (oil-rich) to beige (oil-poor) in colour. The structure of the Piceance Creek basin is very simple with the beds dipping gently towards the geographical centre, and with very few major faults. Interspersed throughout this relatively uniform sequence are occasional thin beds of volcanic tuff and sandstone which form harder layers and are often used as geological marker beds.

Because of the potential economic value of the US oil shales (4×10^{14} barrels of extractable oil) there has been a considerable amount of geological research on their nature and origin which is however far too extensive to quote here in detail. Good descriptions of the geology and mineralogy are given elsewhere[33,34,35,36].

6.2.3 US Working Methods

While all of the British oil shales have been produced from conventional mines similar in scale to the smaller coal mines, American production methods are likely to be different both in scale and types[37]. The traditional method of shale mining followed by retorting at the surface will be used in some projects although when fully developed this will entail large scale drift mining with faces up to 30 m high using room and pillar methods. The retorts to be used are very much larger than those previously developed and are constructed on site at the mine entrance with direct

FIGURE 6.4 General geological succession of the Oil-Shales of the Piceance Creek Basin, Colorado.



transportation from mine to retort. Alternatively, at other sites a modified in-situ (MIS) retorting process will be used. This involves mining out an area at depth and explosively fragmenting a large volume of rock above this to create a rubble pile which is then ignited by burners raising the temperature to about 480°C. Once this temperature is reached the ignition is continued by air injection, the oil collected in a sump at the base of the pile and pumped to the surface. The shale removed during the initial mining operation will be retorted using the standard surface methods.

These large scale methods of extraction are only applicable because of the scale of the geological formation. The consistency and thickness of the shales mean that almost all of the mined horizons yield oil even with a very high working face, and the simple geological structure allows access and space for the development of large drift mines.

6.3 Mineralogical Samples

6.3.1 Scottish Samples

Approximately 1 kg samples of oil shale have been collected from almost every oil shale exposure currently available in Scotland. Because of the soft, easily eroded nature of the rock there are very few exposures indeed and some shale seams could not be sampled at all. Seven of the seams have been sampled, including (because of its relative importance to the industry) four Broxburn shales from different localities (see Figure 6.1). Additionally, one sample of Broxburn Marl was also collected and analysed because of its similarity to the American rocks (other than in its oil content) and as an example of the type of rocks which may have been encountered during mine development. A list of the samples and their precise locations is given in Table 6.2.

TABLE 6.2

SAMPLES OF SCOTTISH SHALE ANALYSED

		Ordnance Map Sheet 65 Reference
1.	Pumpherston Shale, S. Queensferry, Shore section	141.785
2.	Camps Shale, S. Queensferry, Shore section	138.785
3.	Dalmahoy Shale, S. Queensferry, Shore section	143.786
4.	Dunnet Shale, West Calder, Harwood Water	027.630
5.	Dunnet Shale, West Calder, Harwood Water	027.631
6.	Broxburn Shale, West Calder, Harwood Water	026.626
7.	Raeburn Shale, West Calder, West Calder Burn	004.620
8.	Broxburn Shale, Mid Calder, Linhouse Water	080.673
9.	Broxburn Shale (Curly), Mid Calder, Linhouse Water	078.668
10.	Broxburn Shale, Mid Calder, Linhouse Water	078.668
11.	Broxburn Marl, Mid Calder, Linhouse Water	079.671

6.3.2 American Samples

Samples were collected from the sites of two pilot projects in Colorado (see map Figure 6.3). Four of the samples (Nos. 1-4) analysed were from the C-b tract at an MIS site operated by the Cathedral Bluffs Shale Company, a partnerhsip between Occidental Oil Shale Inc and Tenneco Shale Oil Company. The samples collected were from a 3 metre thick sequence immediately below and including the

Mahogany Band which had been mined out prior to the MIS retorting. Included in these samples (No. 4) is a thin bed of volcanic ash typical of those found at various points throughout the sequence.

A further three samples (5-7) were analysed from sections of the R6 Zone below the Mahogany Zone which had been mined out prior to MIS retorting at the C-a tract operated by the Rio Blanco Oil Shale Company, a partnership of the Gulf Oil Corporation and the Standard Oil Company of Indiana (AMOCO).

In addition, one sample of oil shale (Mahogany Zone) from Anvil Points, the mine supplying the Paraho test retort (Dept. of Energy) was analysed (sample provided by Dr. L.M. Holland, Life Sciences Division, Los Alamos National Laboratory). A list of these samples is given in Table 6.3.

TABLE 6.3

SAMPLES OF US SHALE ANALYSES

1.	Mahogany Band	Mahogany Zone
2.	Medium Grade Shale	Cathedral Bluffs Oil Co. C-b Tract Colorado
3.	Low Grade Shale	
4.	Volcanic Ash Bed	
5.	High Grade Shale	R6 Zone - Retort No. 1 Rio Blanco Oil Shale Co.
6.	Low Grade Shale	C-a Tract, Colorado
7.	Volcanic Ash Bed	
8.	High Grade Shale	Mahogany Zone, Anvil Points, Paraho Test Site

6.4 Analytical Methods

Approximately 10 g of each sample was coarsely crushed and then ground in an end-runner mill for approximately 30 minutes.

Ash contents of the rocks were determined after incineration at 380°C and at 700°C in a muffle furnace.

The analytical methods for the mineralogy have been described in detail elsewhere[38]. Infrared spectrophotometry (IR-KBr disc method)[39] was used for quantitative analysis of quartz, mica and kaolinite, the first two in 700°C ash and the last in 380°C ash, using IOM routine standard minerals (A9950, X1387, X2242)[38].

X-ray diffractometry (XRD) was used for quantitative or semi-quantitative analysis of quartz, kaolinite, mica, plagioclase feldspar, orthoclase feldspar, analcime, pyrite, dolomite, calcite, siderite and gypsum in raw dust or in 3800C ash. Corundum (Al_2O_3) was used to calibrate external standard minerals and was mixed in 3:1 proportions with 0.75 g samples of the powdered shales prior to integrated intensity measurement of characteristic diffraction peaks of specific minerals. Comments upon the selection of standard minerals and their appropriateness for these analyses are given later. A list of the minerals identified by XRD and their characteristic diffraction peaks is given in Table 6.4.

TABLE 6.4

Minerals detected by X-ray diffraction, with characteristic diffraction peaks

Mineral	Characteristic Peaks (Cu Kα radiation) °2θ		
Quartz	26.67	50.2	59.2
Kaolinite	12.4		
Mica	8.8		
Dolomite	31.9		
Calcite	29.4		
Plagioclase Feldspar	27.88	28.03	
Orthoclase Feldspar	26.9	15.1	
Analcime	26.0	15.8	
Pyrite	56.38	33.0	
Gypsum	31.1	11.6	
Siderite	32.1		

6.5 Results

The results of the mineralogical analyses given below in Table 6.5 are those selected on analytical and mineralogical grounds from those duplicated by different methods, which are discussed below.

TABLE 6.5

Percentages of total ash and minerals in shale samples

Colorado Shales

	1. Ma	2. Mec	3. Low	4. Ash	5. Hig	6. Low	7. Ash	8. Hig
% Ash 380°C	49.2	81.8	92.2	95.3	75.7	94.5	77.3	66.3
% Quartz XRD	7.2	7.4	14.8	21.5	6.4	11.4	10.8	9.3
% Kaolinite IR 380°C Ash	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	Tr
% Mica IR 700°C Ash	4	n.d.	n.d.	n.d.	6	n.d.	9	8
% Calcite XRD	2.5	n.d.	8	Tr	3	Tr	2	n.d.
% Dolomite XR	2.5	21	17	Tr	19	27	15	20
% Siderite XRD	Tr	n.d.	n.d.	Tr	Tr	n.d.	n.d.	n.d.
% Plagioclase Feldspar XRD	8	11	8	35	7	9	15	3
% Orthoclase Feldspar XRD	Tr	Tr	Tr	Tr	Tr	14	Tr	5
% Analcime XRD	Tr	Tr	n.d.	2	5	2	n.d.	15
Other Minerals XRD	Tr P	Tr P	Tr P	-	-	Tr P	Tr C	-

Scottish Shales

	1. Pumph.	2. Camps	3. Dalmahoy	4. Under Dunnet	5. Dunnet	6. Broxburn	7. Raeburn	8. Broxburn	9. Broxburn	10. Broxburn	11. Broxburn Marl
% Ash 380°C	57.8	66.9	70.0	74.2	74.4	72.0	56.2	59.8	69.1	75.5	67.0
% Quartz XRD	8.4	8.3	14.0	16.4	12.5	14.3	8.5	7.7	14.0	14.0	12.0
% Kaolinite IR 380°C Ash	40	15	22	25	32	31	34	10	17	13	1
% Mica IR 700°C Ash	20	9	20	23	24	23	19	33	28	37	n.d.
% Calcite XRD	n.d.	22	Tr	Tr	Tr	n.d.	Tr	Tr	n.d.	Tr	23
% Dolomite XRD	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	4
% Siderite XRD	2	2	Tr	Tr	Tr	Tr	n.d.	Tr	5	6	n.d.
% Plagioclase Feldspar XRD	n.d.	Tr	Tr	1	1	Tr	n.d.	Tr	1.5	Tr	7
% Orthoclase Feldspar XRD	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
% Analcime	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1
Other Minerals XRD	1% P	1% P	Tr P	Tr P	Tr P	Tr P	3% P	1% P Tr C	Tr P	Tr P	2% P

Tr = trace
n.d. = not detected
P = Pyrite
C = Gypsum

6.5.1 Ash Content

The ash content determined by incineration at 380°C is preferred since higher temperature incineration (700°C) is likely to lead to breakdown of carbonates, giving an overestimation of the combustible fractions while low temperature incineration is very time-consuming and the end point is impossible to determine accurately. The results, as expected, show a range of ash contents which generally reflect the oil yield of the shales. In the American samples, No. 1 (Mahogany Bed), the richest shale, has the lowest ash content (49.2%) while the lean shales, 3 and 6, have higher ash contents (92-95%). The Scottish shales, in comparison, all fall within this range.

6.5.2 Quartz

The quartz content as determined by X-ray diffractometry is preferred over the IR results, primarily because of the influence of particle size on the latter analyses, and especially since, in contrast to airborne dusts, there is little information or control on the particle size of the quartz in the samples. The range of quartz contents shown in the US shales, from 14.8% to 6.4% also reflects the ash content and oil yield, and although the richer shales contain less quartz than the average Scottish shale (11.8%), the general quartz content is very similar. As expected, the ash beds from Colorado generally contain more quartz than the surrounding rocks.

6.5.3 Kaolinite

The kaolinite content determined by IR in 380°C ashes has been shown in the past[38] to be more reliable than that determined by XRD because of the problems of preferred orientation in sample preparation in the latter method.

The results using IR show that none of the American shales contained any detectable kaolinite, although 1% was determined in Sample 8 by XRD. In contrast, the Scottish shales contained major amounts of the mineral (with the sole exception of sample 11, the Broxburn Marl) with an average of 24% and a range from 40% to 10%.

6.5.4 Mica (Illite)

The mica content determined by IR analysis of the 700°C ash has been selected as the most reliable in spite of problems about suitability of the standard minerals. Mica was not detected either by IR or XRD in half of the American shales, while the amounts in the remaining rocks was generally low (<10%). The mica content of the Scottish shales appeared to be considerably higher (average 24%), although the results are difficult to interpret. In general terms the XRD analyses confirmed the IR results, but they did indicate the presence of considerable amounts of illite-smectite mixed layer silicates in the Scottish rocks. These unusual sheet silicates are related to the true micas but are quite different in their layer structure to those normally encountered in UK coal mine dusts for example, and the standard minerals used in IR at IOM may not give more than a general indication of their amounts in the rocks.

6.5.5 Carbonates

Given the assemblage of different carbonate minerals in the shales (particularly the American ones[35,36]) it was not considered feasible to use any method other than XRD for their analysis. The selection of standard minerals was also difficult in view of the known variability within these minerals, particularly with the dolomite, and there is no easy way of determining whether the calibration factors eventually used were appropriate for this range of rocks.

Nevertheless, the difference shown in these results between the shales are quite clear.

The American shales were generally very rich in carbonates, averaging 20% calcite and dolomite with dolomite very much the predominant carbonate mineral. The Scottish shales generally contained only trace amounts of carbonates although the Camps shale unusually contained over 20% calcite whilst the Broxburn Marl contained a similar amount.

6.5.6 Feldspars

Feldspars, both plagioclase ($NaAlSi_3O_8$) and orthoclase ($KAlSi_3O_8$), have only been determined by X-ray diffractometry. The choice of an appropriate standard for calibration was difficult because of the scarcity of pure mineral standards of known composition. The plagioclase feldspars form a solid solution series and, although those of the American shales are reportedly albite, there is little published information on their precise composition and none on those of the Scottish shales. The standard eventually used was probably slightly different in composition, and may therefore not be appropriate.

The results nevertheless show a clear difference between the American and Scottish shales. Plagioclase feldspar was ubiquitous in the American shales with an average of 8% (range 3-11%) although the volcanic ashes contained more (up to 35%), while the Scottish shales contained only small or trace amounts. The exception to this was again the Broxburn Marl which contained 7% plagioclase feldspar.

The difficulty with standard minerals was greatest with the orthoclase feldspar for which no suitable standard could be obtained and eventually an arbitrary calibration factor was used. This is not considered important since only two

American shales (Nos 6 and 8) contained more than trace amounts and none at all was detected in the Scottish Shales.

6.5.7 Analcime

The presence of analcime ($NaAlSi_2O_6.H_2O$) could only be determined by XRD because of interference from feldspars, micas and other minerals in IR. The same problems with standard minerals were experienced with analcime as with the other minerals, but in this instance a standard pure mineral from Scotland was considered suitable for calibration. The results again show that while the American shales frequently contained trace or small amounts and occasionally very major amounts (No. 8), none could be detected in any of the Scottish rocks except the Broxburn Marl (about 1%).

6.5.8 Other Minerals

Pyrite (FeS_2) was a common accessory mineral in most of the shales examined.
Gypsum ($CaSO_4.H_2O$) was detected in two shale samples.

6.6 Discussion

If the general quality of the results given in Table 6.5 is judged by the proximity of the total analysed mineral content to the ash content then it is apparent that while for the Scottish samples the correspondence is good, it is much less so for the American samples. This probably reflects the difficulties mentioned earlier in the selection of standard minerals appropriate to those found in the rocks. In particular, while the quartz analyses for the US shales are similar to those published elsewhere[33] the results for dolomite are signficantly lower. The calibration eventually selected was somewhat arbitrary, since there is no real way of determining the precise XRD characteristics of the minerals in the rocks, and it is accepted that an alternative mineral standard, had it been available may have been better. Similarly, although there is less analytical evidence for comparison, it is probable that the results for the plagioclase and orthoclase feldspars are also lower than the real contents. Nevertheless, in spite of these problems, the contrasts and similarities between the two sets of shale samples are still evident.

The most striking contrast is the almost total absence of kaolinite and mica from the American shales whereas these minerals predominate in the Scottish shales (whether the sheet silicate is mica or illite-smectite). Likewise, the virtual absence of carbonates, analcime and feldspar from the Scottish shales contrasts markedly with their predominance in the American shales. On the other hand, the shales are very similar in terms of total ash, quartz and minor accessory mineral contents. From this it is apparent that the Scottish shales contain appreciably more total silicate mineral than the American shales.

The similarities and contrasts between the two rock suites are interesting from a geological point of view. Both groups of shales were deposited in relatively quiet, probably shallow, distal, lacustrine or lagoonal environments. The sediments originally accumulated were probably very similar in their mineral assemblages. Neither plagioclase or orthoclase feldspar nor analcime usually survive the weathering processes involved in reaching such an environment, and generally in rocks such as these they are largely authigenic (i.e. formed in-situ from previously deposited minerals). It would furthermore be extremely unlikely that no kaolinite or mica was received into the Green River Shale basin during the whole period of deposition. The probable explanation for the differences in mineralogy therefore almost certainly stem from differences in diagenetic (low temperature chemical reactions) processes to which sediments were subjected after deposition. The increasing alkalinity of pore water in the sediment and the development of a chemically reducing environment which would be necessary for the precipitation of the carbonates may also lead to the chemical reaction of the sheet silicates with the same pore fluids to produce the feldspars and the analcime. Such changes in chemical conditions during progressive burial are common, especially in areas with abundant decomposing organic matter and with relatively stagnant water. It is interesting therefore that in the Scottish shales (lagoonal or estuarine deposits) the carbonate content is low and the sheet silicate content is high, except in the Broxburn Marl where the presence of high carbonate content is matched by low kaolinite and mica content, relatively high feldspar content, and the only analcime in the Scottish samples.

These results are of interest when it comes to discussing the likelihood of their inhalation causing pneumoconiosis. Unfortunately, the exact mineral composition of the rock is not always reflected exactly in the dust generated by mining it. Nevertheless, some guidance may be obtained and indeed one previous study has shown that the dust extracted from the lungs of Scottish shale miners was very similar in composition to that of the rock they mined[40]. In general it may be assumed that high levels of quartz (over about 10%) are potentially harmful, though this mineral may be rendered somewhat less toxic if inhaled in association with other minerals such as kaolinite or micas. These points are commented on further in Volume 2.

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