Chapter 10

Techniques of underground quarrying: 3. Support of the roof and spoil management

These two aspects are considered together since spoil management was an integral part of the roof support, either directly providing support by being banked, packed or chocked to the roof or, indirectly, by providing lateral support to pillars which supported the roof. It is unlikely with the relatively high workings at Combe Down and often slender pillars, that without substantial lateral support, they would have been as stable as they were.

Support of the roof

The quarry roof

The roof, often locally termed the ceiling, was ostensibly the simplest feature of the quarries. It was usually either one of the picking beds or, except where it appears to have been absent in the north-eastern areas, the bastard or capping stone. The latter was a hard bed of limestone formed along bedding planes that provided a clean parting. It provided a fairly strong roof under which the quarrymen could work in relative safety where gaps between pillars were not too extended. The first bed of freestone beneath the roof in most of the quarry was usually thin and unproductive for quarrying, and in parts of the quarries, for example above the Brow cartway in East Firs and sometimes where corbelled and direct pillars were used, it was left in as the roof.

Observation of the roof strata can provide clues to quarrying methods. In both Firs and Byfield a change in roof bed (leaving part of the former picking beds *in situ*) resulted from the introduction of jad slots and corbelled and direct pillars, while the bastard bed of hard but well-jointed stone in the roof of the Byfield and West Firs area seems to have been replaced by thin-bedded limestones in the East Firs, in which frequent collapses occurred. Variations in roof height were used during archaeological recording throughout the quarry complex to determine the limits of individual quarrying areas and changes in quarrying practice.

Natural features of the roof, such as the joint pattern, could create problems for quarrying and thus often dictated the working process. The joint pattern at Combe Down had two principal systems, the major set orientated roughly at 70º across the Down, and the other major set at 140º. Further joints appear to have run parallel to the escarpments, possibly due to cambering of the strata. These directions dominated the pillar orientations, sometimes aligned, more often crossing the alignment. The fractures often formed a close interlocking pattern on the roof underside, but observation of pillars suggests this pattern did not always extend downwards through the more massive freestone beds, nor, where visible at falls, upwards into the bastard bed. The thin beds above the worked stone seem to have been particularly fractured and thus the situation as seen during the Stabilisation Scheme may have been due partly to post-working stresses.

The combination of joints and weak bed partings led to delamination of beds and, if the roof spanned a large number of joints, this could cause roof-hanging and either slow or catastrophic collapses. This must always have been a major problem, and there were many instances of roof collapses which had occurred during and after quarrying, leaving roof voids and the gradual onset of the void working upwards through each of the sedimentary beds, or through to the surface forming a crown hole. Evidence of contemporary collapse, over, for example, a cartway, took the form of removal of a collapsed material or diversion around a fall. It was obviously the function of pillars to support the roof, but often substantial effort was expended to reduce the incidence of falls of roof, including the use of rubble stone packs, infilling with spoil, and timber sprags and chocks, and in the post-quarrying period features such as road, house or drainage pipe support packs or walls were installed.

General aspects of pillar design and spacing

There must always have been careful consideration as to what to leave behind as pillars, which typically took up 10-15% of the total stone available and whose function was to secure the roof. Except in the true arches of closely spaced apophygate arches, seen at some entries and occasionally in workings, the pillar spacing would impose tensions in the 'beam' of the ceiling beds exposed between them. Because of the small spacing of the jointing normally found, this would tend to delamination and downward arching and collapse if excessive. What was considered excessive was determined by experience. The spacing would also determine the load upon pillars which were prone to failure, because of close jointing and up to three sets of joint directions as well as faulty execution of design. Fortunately the process of failure of roofs and pillars was often slow, and many weaknesses were of marginal importance during actual working, though becoming obvious a century or two later.

The early apophygate pillars (see below), which seem to have developed from arches by stretching the gap between the arcs, aimed to reduce the effective beam span by spreading the pillar support at the top. This unfortunately placed a heavy load on the thin extremities of the apophygate pillar, which eventually led to spalling, though it may have been obvious during the time of working. Introduction of the various forms of the jad slot to replace picking bed removal left the topmost picking bed or beds in place, which was probably more stable than the overlying bastard bed. This was used in conjunction with the corbelled pillar, which clearly was intended again to reduce the effective span between pillars, but was equally prone to failure during working or under post-working stresses. Towards the end of the 18th century, in Allen Estate Phase III times, this was addressed by the use of direct pillars with vertical sides up to roof height which seem to have been proved the best type. Pillars which were in a state of structural failure with faces spalled, and pillar fractures developing were described during the Stabilisation Scheme as degraded pillars, from which failure (collapse) could be prevented only if the roof load was carried on adjacent pillars.

With all the pillar forms, an equal spacing along lines of equally sized pillars enhanced stability. Because joint problems sometimes prevented this, over-sizing was necessary for permanent stability. Ideally the pillars would be regular, probably rectangular, with the long direction placed at right angles to the predominant joints to reduce the buckling effect. In practice the predominant joints were used to assist extraction, so the long sides of pillars frequently were bounded by the predominant joints. This could be ameliorated by staggering successive pillars along joints, as was the case in some areas of pillars in East Byfield, whose plan (see Figure 1.9) shows a slightly curving delineation as a result. This staggering would have prevented collapses along lines of particular weakness.

This may also be the reason for limited length of views in many areas, with pillars deliberately left, possibly as the end of working faces, more or less across the room being developed. What we have termed long and boundary pillars – long lengths of pillar which often seem to denote different workings or phases of workings, as that under Combe Road – may have had a similar function. Conversely, in James Riddle's workings, Quarry 518, developed soon after 1900 in East Byfield, the pillars were carefully aligned along a major open joint, probably to facilitate the use of saws. The lack of the collapse this practice might have created there may partly have been due to the regularity of shape and spacing which sawn pillars promoted.

Pillars were the most variable conspicuous features of the quarries. Archaeologically they were a major source of information about quarrying methods, each pillar in effect representing a small portion of the actual working face. The setting and size of pillars appears to have been entirely empirical, depending on the experience of workman and supervisor and it is clear that this was often barely adequate and certainly not consistently applied. Changes in pillar forms and in their setting, where these could be isolated from natural features, indicated changes in the quarrying method and could, with caution, allow definition of separate working areas and phases of activity.

There was clearly a limited variety of pillar forms aimed at, and within those varieties some were more or less regular, others highly irregular. Pillar forms and the degree of regularity resulted, to a considerable degree, from the local jointing characteristics due to the two principle systems of joints, the third subsidiary system, and the angles at which they crossed, and because they were utilised by the quarrymen both to break into the beds and as natural faces to work to. The extreme cases were pillars which may also have been affected by minor movement, possibly from faults. These included the inclined long curved surfaces on sailed pillars, a characteristic form from faulting (Fig. 2.7), and others where successive beds have 'stepped aside', possibly the result of post-working movement. Most pillar surfaces or faces were either natural or were slightly modified joint faces which were relatively uninformative, though highly variable.

Although arched forms of support in pillars are found in underground quarries elsewhere, for instance at Browns Folly at nearby Monkton Farleigh in Wiltshire and at Beer in Dorset, the particular extended apophygate form at Combe Down led to a highly idiosyncratic landscape apparently not described elsewhere. Other types can be seen in many locations, in both underground mines and quarries.

Pillar classification during the archaeological survey

A wide range of pillar forms were initially classified in order to describe what was being observed. This was subsequently simplified to a few basic forms, with a range of what might be termed 'irregularities', largely resulting from joints and fractures or, occasionally, mistakes. The principal pillar types comprise; arched and apophygate pillars; corbelled pillars; direct pillars and long, rib or boundary pillars. Variations noted within the quarry complexes included entabled, sailed, tapered and irregular pillars (Fig 10.1).

Apophygate pillars

Aside from the unusual and precocious use of corbelled pillars in the *c* 1725 workings of the E4 Stub, Quarry 2347 (see Chapter 12, Case Study 2)

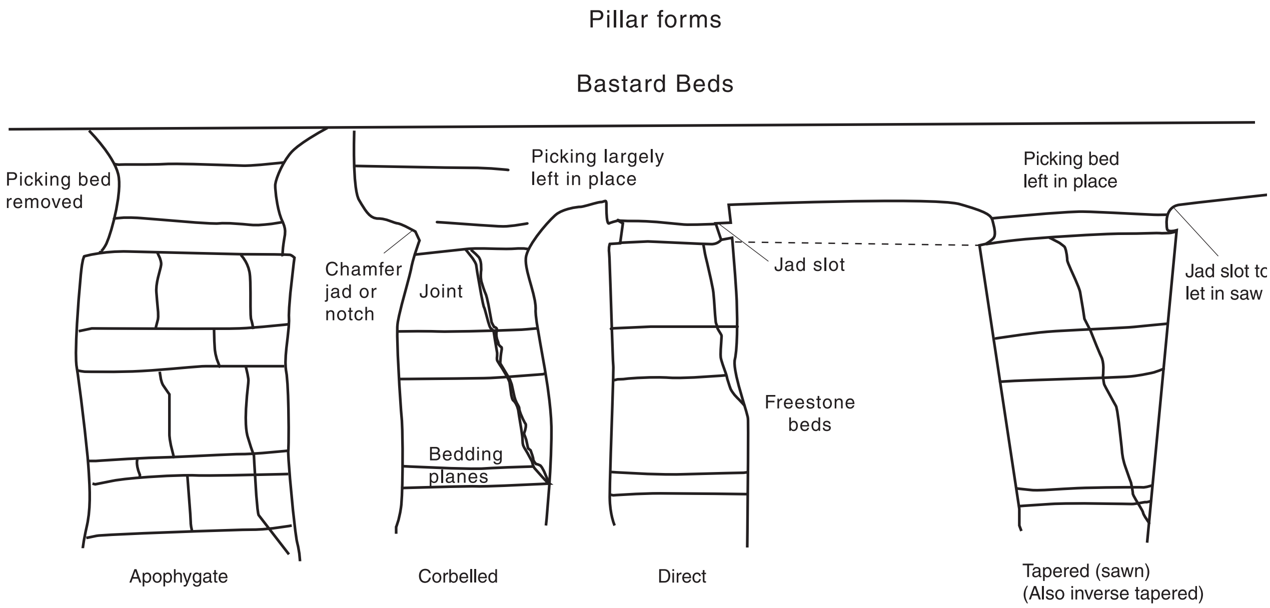

Fig. 10.1 Various pillar types

under the south end of The Avenue, the earliest pillar form generally used at Combe Down appears to have been the apophygate. This form seems to have resulted from the extension outwards of an arched form. Several areas of such pillars are found near to the southern outcrop which, because some cases appear to have been abandoned soon after Allen's takeover, pre-date his involvement, so it seems he may have continued rather than initiated underground quarrying at this location. Their use seems to correspond to the pre-Allen or Allen Phases (I and II), up to around 1750 (Figs. 10.2 and 10.3). A stone block abandoned close to one such pillar had the date 1734 written on the face and the date 1730 occurs on another in East Firs.

Though apophygate pillars were most common at the southern margin, they also occurred in underground quarries on the west and north side of Sheeps House Quarry. Likely early examples generally seem to be those in small working areas, where work was abandoned after Allen's takeover. Allen may well have extended other existing areas. Other examples were found in the Byfield Quarries 505, 516, 519, 910, 911, 914, 2349, and 2398 and Firs Quarries 2200, 2204, 2331, 2339, 2341, 2345, 2346, 2350, 2352, 2360, 2369, 2371, 2384, 2385, 2386, and 2399.

It is a highly distinctive pillar form with a slightly hourglass shape with a top resembling the *apophyge* or 'curving-out' seen on classical columns (Fig. 10.4). The shape was intended to increase the bearing area under the roof and was formed by hacking out the three or four picking beds from around the pillar just below the roof level. Between the top outer edge of the apophygate pillar the roof was flat, following a bedding plane. The beds below the picking bed appear to have had joint faces predominating, with a characteristic narrow lip or collar at the intersection below. The pillars could be apophygate on one or many sides and a few were roughly corbelled (see below) on other edges of the pillar as well as having apophygate features. In the more northern areas of their occurrence in Central Byfield, the curvature of apophygate pillars seems to have been reduced, so that some pillars appeared almost direct in style.

Apophygate pillars were sometimes worked in such a way as to form crude arches with one or more adjacent apophygate pillars. The true arched form was found close to entries, for instance the eastern entry at Jones' Quarry at Central Byfield. It would have been especially useful near the margin of the outcrop where weathering and opening of joints was most critical. In the outer areas of Byfield the room openings between pillars were only 2-4 m, and the apophygate pillars formed an actual, or close to actual, arched roof for the rooms. Further within the quarry the distance between pillars increased to at times over 10 m, so the continuous arched form was lost. The wide spacings and over-narrowing of pillars also seen in some parts were probably unwise, sometimes resulting in considerable instability. It was apparent in Byfield that collapses had taken place before underground haulage ways went out of use. In Firs Quarry the apophygate pillars were again close enough together sometimes to form arched roofs, but, especially in East Firs the gaps between pillars were widened and this area had the highest density of 'high hazard areas' noted in Hawkins (1994) report (Fig. 10.5). It is possible that collapses seen notably in apophygated areas of East Firs caused Allen sufficient concern over deaths around 1755 to begin surface quarrying, as John Wood claimed in 1765. It may also have stimulated the change to corbelled pillars likely at about the same time (see below and Chapter 3).

Fig. 10.2 Apophygate pillars within Central Byfield (Quarry 505). The pillar on the left is severely degraded

Fig. 10.3 Apophygate pillar in East Firs close to The Brow cartway in Quarry 2339. This is an example outside Allen's quarrying area

The distinctive hourglass pillar shape was sometimes emphasised by the deterioration of the pillar face, either because where they were located close to the quarry mouths or to vertical shafts, where flows of cold air produced frost damage, or from degradation due to roof load. Spalled, small tile-like limestone fragments fell from the pillars and were deposited around the base. Evidence for spalling of this sort and the damage to possible toolmarks by degradation of pillar faces was recorded within Allen period Byfield Quarry 505. Of the 70 or so apophygate pillars located in the central part of the Allen area there, only 10 had surviving evidence of tooling on the faces and well-preserved toolmarks were found on only one apophygate pillar. The toolmarks were represented by an area of curving pick marks on the underside face of the apophygate curve. The toolmarks emphasised that this form or shape of pillar face was chosen by design, rather than as a consequence

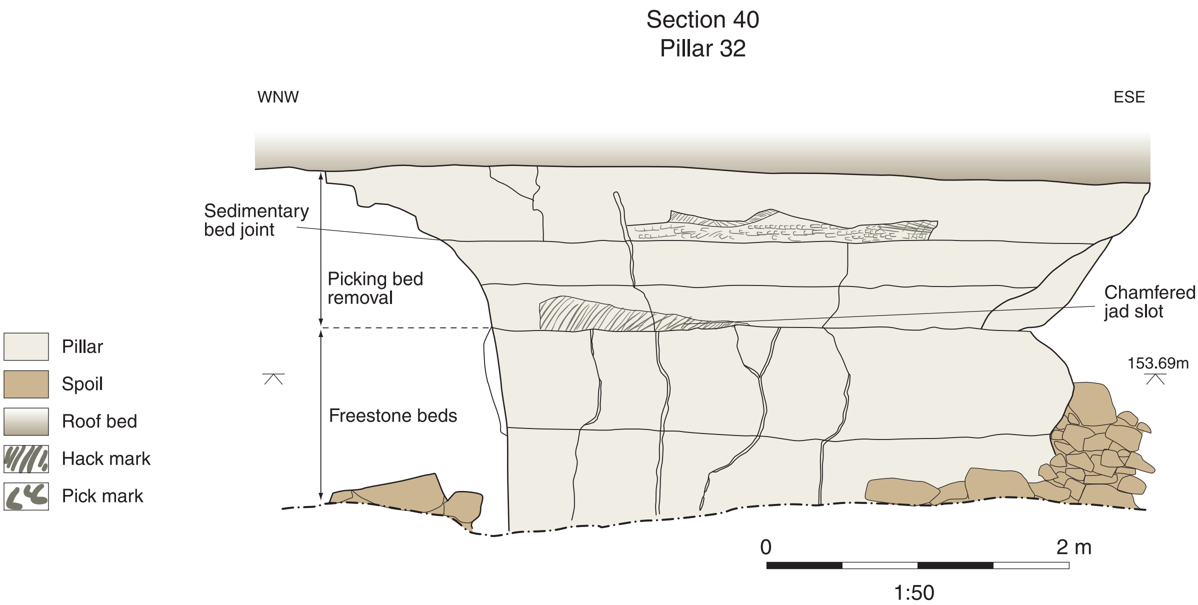

Fig. 10.4 Section of the top of an apophygate pillar including a small chamfered jad

of post-quarrying frost damage or spalling or delamination through pillar load. Toolmarks would also have been lost to the reduction of pillars during subsequent later quarrying and/or Bath Stone.

In the succeeding phases of working, joint faces were left on pillars as the norm, but this had declined before or by the 19th century, first with two faces normally cut by vertical jad cutting or otherwise breaking or sawing, increasing the regularity of the pillars, and, finally, by sawing on all, or nearly all faces, providing, in the final stages of working, almost symmetrical pillars. A regular vertical form of pillar will usually provide the most efficient form of support. Because of the joints and fractures and the methods used to produce them, the desirable regularity in pillar form was rarely achieved, and a very wide range of distortions existed which either required larger or more pillars, or led to weaknesses in the degree of support.

Corbelled pillars

Corbelled pillars usually occupied very limited areas as an outer ring to apophygate pillars, though their earliest introduction was in the E4 stub Quarry 2347, where the corbels projecting at the top of the pillar were more substantial than was usual later (Fig. 10.6). In Byfield Quarry 505 a transitional form of pillar with both apophygate and corbelled style developed (Fig. 10.7). The wider use of corbelled pillars may have resulted from the general intro-

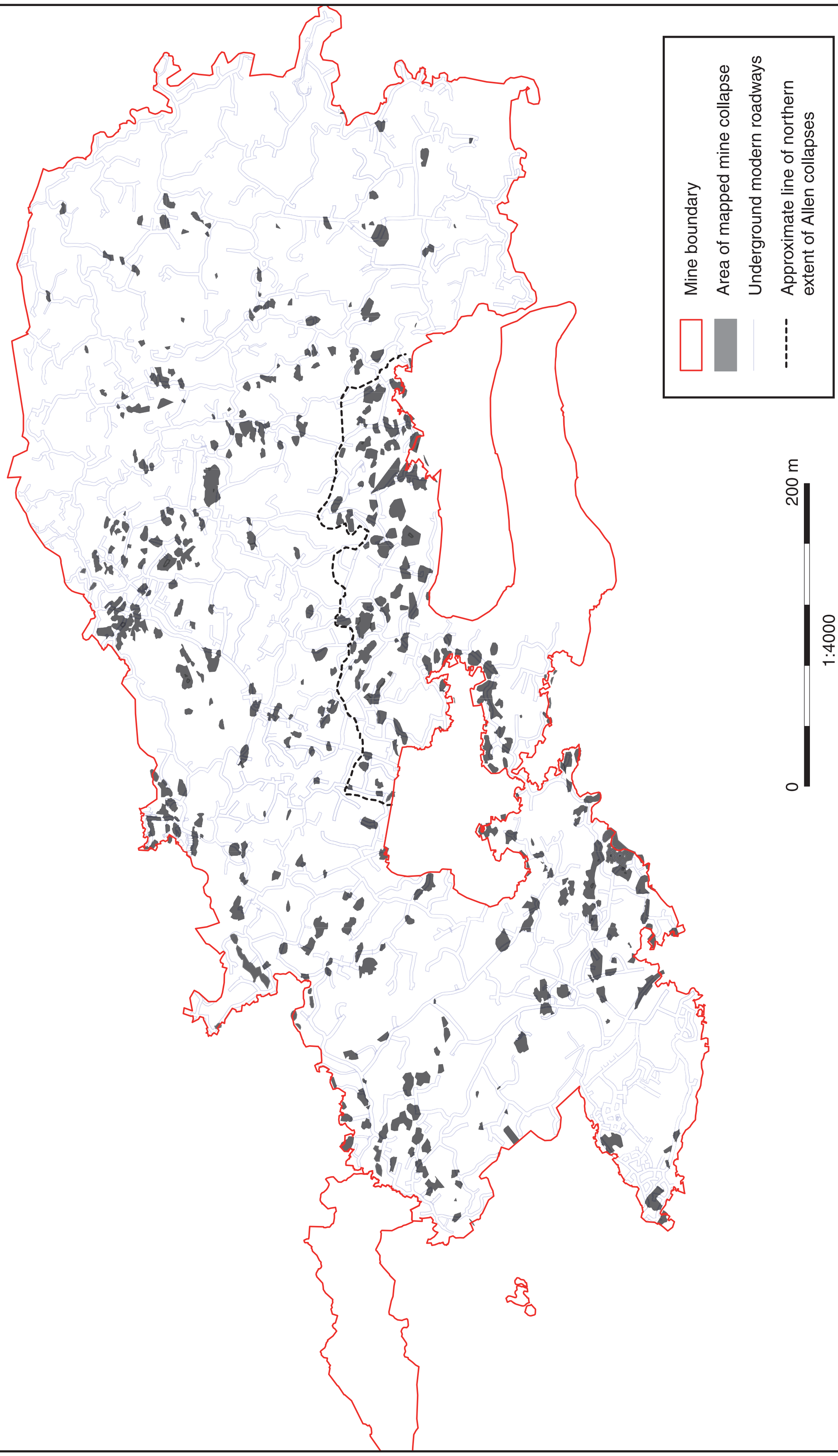

Fig. 10.5 Major areas of roof collapse in Byfield and Firs. Note the high concentration in the southern area of East Firs, part of the Allen Phase II workings (after Hawkins 1994)

Fig. 10.6 Corbelled pillar in Byfield

duction of parallel or chamfered jad slots and notches as part of picking bed removal and perhaps also from a desire to continue the supposed advantages of apophygate pillars. In the parallel jad slot the near horizontal top and lower surfaces went back usually to a joint with the top surface a single bed or two beds below the main roof level. In chamfered forms the horizontal lower part of the slot was cut into the middle or lower of the three beds typical of the picking beds, with the top-surface angling down to either a joint face or the lower bed surface, allowing easier access for a short-handled pick. The term 'notch' was used for when both surfaces of the cut diverged significantly from the horizontal, and where the jad slot was reduced in height to generally a single, or perhaps two rows of pick marks. By driving a wedge into the bed parting below, a section of bed was lifted and/or broken at the back of the cut and could be removed. The section of bed above was left protruding as far out as the next joint as an 'ear' or corbel. Its use seems to have led to the gradual abandonment of removing the full-height picking bed for access and the junction of apophygate with corbelled areas was sometimes seen as an under-slung projecting ledge across the intervening room. Such pillars were described as 'entabled', and good examples of this type were noted on the periphery

Fig. 10.7 Transitional form of apophygate and corbelled pillar in Central Byfield (Quarry 505)

Fig. 10.8 Corbelled pillar just west of Firs Shaft, with inadequate support in the core width below

between the Quarrying Areas 505 and 517 in the Byfield Quarry.

The use of the chamfered or parallel jad was probably speedier than than fully forming the pillar in the picking bed. Structurally the corbelled pillar acted in much the same way as the apophygate pillar. A wider area around the top of the pillar was protected and in similar fashion this may have led to a tendency to provide too small a pillar below (Fig. 10.8). Corbels frequently developed a split in line with the main pillar-side, along the natural joint face, rendering them structurally useless and often dangerous. It is possible the vertical split was not developed fully during mining and was a post-quarrying fracture as the superimposed loads adjusted. In some cases corbelling may have resulted from Bath Stone rather than original design and many other examples are possible but hidden by dumped spoil. The insertion of a vertical timber prop, or a small stone pack positioned under the corbel sometimes provided additional support and is a clear indication of concern during actual working.

The introduction of corbelled pillars generally was difficult to date, but considerations of the position of later leases and known periods of inaction at Byfield suggest their introduction in the middle of the Allen Phase II, probably continuing into Phase III when they were gradually superseded by direct pillar forms, with only the occasional occurrences, in isolation, of the formerly widespread corbelled pillar use.

Direct pillars

Direct pillars were the most common type found in later workings (Phases IV-VI), and proved the best type structurally (Fig. 10.9). Ideally they had vertical sides with either a joint face or a carefully vertically broken side with bed end faces in line from floor to roof. Many cases, however departed from this ideal and overly narrow or other irregular forms were common (Fig. 10.10). The introduction of the direct pillar, alongside corbelled pillars, appears to have coincided with the common use of horizontal jad slots with near-parallel faces and usually, as with corbelled pillars, the abandonment of the full-height opening-out of the picking bed. With the almost simultaneous systematic use of wedge-and-chip method for the breaking of sedimentary beds and for the removal of blocks from the pillar faces. Fairly regular shaped direct forms could usually be achieved and the later introduction of saws allowed for very regular forms, as was observed in the latest worked areas of the quarries in the later 19th and early 20th centuries.

The introduction of the direct pillars using the jad slot caused a substantial reduction in spoil from the picking beds above, and also largely coincided with the use of the Long Wall with gullet method of working. There appears to have been a transitional period in which both corbelled and direct types co-existed in Phase III, corbelled pillars disappearing almost completely by Phase IV. It is possible this was largely a local development as the structural

Fig. 10.9 Direct pillars in Central Firs (Quarry 2340)

advantage of direct pillars and their simpler method of formation became apparent.

Boundary, rib and long pillars

These terms described pillars which were larger than the normal pillars, particularly in length, but also width. Boundary pillars, as defined during the archaeological survey, were substantial lengths of either lines of long pillars or boundaries un-pierced by full room-sized openings (but sometimes by door-like and window openings) over stretches of linear un-worked ground. Typical rib pillars usually had a square or rectangular section, with the long dimension around three times the shorter, and the shorter usually 1-2 m wide. Long pillars had substantially greater ratios. They were typically found across the line of general working or at abandoned working faces, and may have been deliberately left to provide buttressing as well as roof-support to small quarrying areas.

Division of the wider area of the quarries seems to have been into separate working areas, perhaps on the basis of work teams or, later, leases or direct ownership by individual quarrymasters. Boundaries of areas can sometimes only be indicated by differentiated working methods (for instance types of pillars, or tool markings), but more commonly such divisions were also worked back to a 'long pillar' or 'boundary pillar' pierced only by small access or ventilation openings or 'windows' or 'doors', used either to dispose of spoil into adjacent areas and/or for access or ventilation. These, with a combination of other changes would determine a quarry boundary pillar. However, caution must be given to the fact that some of the perceived boundary pillars may also have been left *in situ* to support a localised geological variation or weakness such as a roof gull or to give additional support to a principle cartway route.

Boundary pillars also served as ownership markers and/or sometimes defined features that were noted on the surface, such as parish boundaries and roads and footpath orientations. An obvious boundary pillar reflecting (in this case) a surface boundary, ran under Combe Road from the south of the freestone outcrop to North Road and divided both Allen's quarry and later quarrying interests in the Byfield workings; during the Stabilisation Scheme it was called the 'Combe Road Pillar'. It was pierced by one or more 'doors' which may have been used for pedestrian access, and was robbed on both sides for much of its length but generally without cutting through. . At the southern end it was much wider and more well-defined, with the northern limits having more piercings and remaining no more than a series of slightly larger and more prominent pillars in the general pillar plan. The earliest Allen working in Byfield was apparently limited entirely to the eastern side, but probably during the later 18th century a new entry was made (from Ralph Allen Yard) and the pillar pierced to form a trackway to serve the western area, even though it was only a few feet away from the earlier entries. The

Fig. 10.10 Section of worked face 3007, an irregular form of direct pillar with narrow core, showing picked and wedge and chip broken surfaces

quarrymen were forbidden in their early 19th-century lease (Chapter 6) to cut through the Combe Road boundary under the northern end of Combe Road as defined by the new east side roadside wall. The terms in that case do not appear to have fully been adhered to. The quarryman, Tanky Elms, (Hall 1984) remembered -

> *. . .that there was a quarry boundary running along* [and under] *the road at Westwells* [Odd Down], *Bath and Portland on the one side and, Sheppards on the other side of the road. Sheppards went over to the other side of the road and had to pay I believe seven hundred and fifty pounds compensation.*

In Firs the equivalent boundary was the Long Drung. The longest rib pillar there as surveyed by Hawkins (1994) seems to mark the 18th-century northward limit of working in the central area of the quarry west of the Avenue, with subsequent working on the east and west margins. The quality of stone in the pillar was lessened by minor fracturing or faulting and it may have been initially a convenient place to stop development northwards. Areas to the north of the rib pillar were subsequently worked southwards during the middle years of the 19th century by entries driven from open quarries north of the North Road. Quality, however, can hardly have been the reason for its survival to the south, where it also formed the northern boundary of 18th-century workings and the south west boundary of the early 19th-century Three Acre Quarry. It bordered a high pillar area with little lateral support from spoil so it is possible there the rib pillars were left to improve stability.

Several other boundary pillars identified during the archaeological recording were used for the hypothetical division of the underground workings into separate quarries (see inside end cover), though in some cases the function may have been to prevent a lateral movement or 'domino effect' and rather than being a legal boundary, they were simply a convenient boundary between separate areas of the same quarry workings. This seems especially true of several such 'boundaries' in the Three Acre Quarry near the Haley Arms. This implies that long and boundary pillars were probably fully understood at the time to enhance lateral stability. Long pillars often formed the sides of Long Rooms and lengths of cartways were also commonly located besides the pillars, undoubtedly for the stability offered.

Irregular pillars

The term irregular is used to describe pillars of unusual form that resulted from either particularly poor, or misconceived workmanship, or from difficult natural circumstances, notably jointing. Saws allowed pillars to be very regularly produced, but in Quarry 2215 in north Central Firs, the pillars were carefully produced with a downward, wedge-like taper so regular and frequent that they must have been deliberate, but were clearly misconceived, as they placed the load on a very small area (Fig. 10.11). Saws were also frequently used for scavenging, cutting into otherwise regular pillars to remove the best thick bed just above or below the spoil-dump level. Many pillars appear to have been severely cut away just below the spoil to a highly dangerous degree which, subsequently hidden, was hard to detect. Particularly bad examples were found in the southern part of East Firs where nearby apophygate pillars also led to instability. Joints produced some of the greatest irregularities, including pillars with major open joints running through them. A pillar in the Grand Canyon in Firs, for example, from one angle appeared twinned, but was regular from the other.

The side piercing at the edges of individual quarry rooms developed windows and openings close to the roof level. In the case of some pillars, additional openings were sawn or wedged below these creating H-shaped pillars. One example was recorded in the mid 19th-century Quarry 2211 and another, in the early 20th-century James Riddle's Quarry 518 was the clearest example seen at the Combe Down (Fig. 2.4).

In Firs Quarry (2215) strongly inclined joints intersecting at a small angle produced long, thin pillars termed by the archaeological team 'sailed'

Fig. 10.11 Tapered sawn pillars in north Central Firs (Quarry 2215)

pillars the ends coming to a sharp edge (Fig. 2.7). They could be part of local fracture systems. Such inclined pillars were liable to be very unstable, and it was perhaps for this reason that work was suspended in that area. Another example of a sailed, sawn, pillar had a deeply picked jad slot in the first bed below the roof to allow access for the frig bob stone saw. The full height of the exposed pillar face was sawn with over 12 beds worked to the contemporary floor level. Other pillars in the quarry had both natural and sawn faces and adjacent sawn pillars showed evidence of horizontal wedge holes and timber sprag supports. Not uncommonly pillars were also cut into at the top further than was probably intended, and rubble-stone packs and timber sprags were then used to support the roof above the damaged section.

Pillar spacing

The spacing between pillars varied greatly, but seems typically to have been about 4-5 m with the largest spans seen in East Firs of up to 13 m. Spacing of pillars and their distribution along joints usually showed regularity on the overall pillar distribution plan produced by Hawkins (1994). However, there was no overall regularity in the workings, due either to variable geological circumstances or to the particular working practices of the quarryman, quarrymaster or freestone mason involved. In some cases there was a surprising lack of common sense and appreciation of personal risk.

Roof and lateral support (other than pillars)

Pillars provided the principal support for the roof and long or boundary pillars often additionally provided lateral support, preventing progressive collapse due to failure of one or more pillars. Given the dubious stability of many pillars with heights of up to 8 m (unusual in mining generally), it is clear that the spoil infilling also provided lateral support, sometimes to the roof, even if only by preventing loose roof blocks descending and destroying the arch effect. Spoil infilling was frequently placed around or between pillars and kept in position by rubble-stone packs, which was clearly done to improve stability as well as the management of spoil.

Carefully built, coursed rubble-packs occurred throughout the workings, but less commonly than in some underground quarries, so it was probably regarded as a method to be used in specific circumstances rather than routinely. Some were contemporary with initial workings, but many seemed to result from re-opening of old cartways for later working. A good example was exposed at the side of the branch cartway along Allen's east cartway in Firs Quarry 2201 when it was re-opened to work Quarry 2202 in the mid-19th century. Here a major collapse was removed, and a massive 1 m-thick by 5 m-high stone pack was constructed by the cartway to lessen the roof span and hold up the remaining roof.

Other less carefully constructed packs of roughly stacked and coursed rubble seem to have been used

Fig. 10.12 Substantial rubble and blocks used to construct the wall near the Hadley Arms under the south side of North Road

Fig. 10.13 Rubble stone mortared packs under a municipal drain running across the surface overhead in West Byfield

to separate areas of quarrying, possibly for boundary purposes or to direct air-flows, and many small packs were built to provide local support where roof stones had slipped or slumped. In one instance in north Central Firs a pack had removed the arch effect and an adjacent keystone block slipped as a result, remaining hanging above the floor. One of the most major coursed-rubble and block packs or walls was built near the Hadley Arms Public House, running below the south side of the North Road. It was in an area noted by Hawkins (1994) as having a roof thickness of less than four metres and sometimes below three, and where a very substantial fall appears already to have taken place. This filled the space between pillars to a height of about 5 m and was chocked under the roof by small stones (Fig. 10.12).

In the area of substantial collapse and risk to the adjacent area, the North Road wall was temporarily discontinued, considered too dangerous to remedy, though it is possible the bad section was under a different quarrying operation. Spoil was used in conjunction with rubble-stone packs to underpin many parts of the North Road. In some cases the packs were built as square 'cribs' and the box-like structures filled with rubble. The road had been undermined largely by entries in the surface quarries to the north. Multiple packs were built perpendicular to and parallel to the road and infilled between with spoil. Some of this was done inefficiently: in one case loose bed-blocks in the roof were held by a pile of small stones resembling a particularly insubstantial way-marking cairn. Substantial packs were built between pillars at Stonehouse Lane Quarry (2219), probably to retain surface quarry spoil in position while a line of mortared-stone packs were built to support the length of a drain in the mid 1920s in West Byfield (Fig. 10.13).

Roof collapse contemporary with working

Roof collapses occurred throughout the Combe Down Quarries. They could involve the falling of an individual block (Fig. 10.14), such as that noted in Quarry 509. More serious collapse due to roof bed separation was noted (Fig. 10.15) above the cartway in Quarry 2211, where one or more of the sedimentary beds of stone just above the roof level had separated from the bed above, but remained *in situ* at roof level. Some collapses were contemporary with the quarrying periods but could also represent post-quarrying episodes. Partial collapses were sometimes held at roof level by the construction of stone packs, stone chocks or timber sprags, and could also be alleviated naturally by the proximity of roof supporting pillars or hinged on adjacent roof blocks.

Roof collapses noted included materials of any size that had fallen to the quarry floor, including localised falls of single roof blocks, other small areas collapse from a single bed, or hundreds of smaller blocks or several roof beds spread over large areas. The depth of collapsed roof bed could

Fig. 10.14 Fallen blocks in Byfield (Quarry 509)

be relatively shallow and spread over a large area or more localised but completely filling a room. Some falls were clearly catastrophic, with a large quantity collapsing at once, or progressive, the roof falling portion by portion over a long period. The former probably often involved thick bastard beds delaminated at roof level, the latter possibly developing later as the void, or 'crown hole' developed upwards into the thinner Twinhoe Beds (Fig. 10.16). Roof collapse was regularly noted at the limits of the underground and the surface quarrying entries whether level or shaft. A good example was recorded in Quarry 2371 where the collapse extended beyond the quarry roof, with roof materials slumping into the underground quarry.

The clearest evidence for contemporary roof collapse was a void in the roof and an absence of associated roof bed materials on the quarry floor, showing that the material had been removed during the period of quarrying. An example of such collapse was recorded above the cartway in Quarry 2200. A flanking stone pack on the western edge of the cartway had been constructed up into the crown hole created by the collapse, suggesting that the collapse had occurred during the mid 19th century, or was consolidated during this period (Fig. 10.17). In Quarry 2211, a stone pack was constructed on a pillar bench at roof level to support an area of roof bed separation. The block still rested upon the pack and the pack had obviously been built to support the roof but it was unclear whether the block had actually separated from the roof during quarrying or later.

Fig. 10.15 Delaminating roof bed in Central Firs (Quarry 2211)

Fig. 10.16 Collapse of Twinhoe Beds in East Firs

Fig. 10.17 Support pack in Central Firs

Fig. 10.18 Pack built on top of fallen blocks in Central Firs (Quarry 2200)

Roof collapse and/or instability surrounding a vertical wide shaft was recorded in the former Ralph Allen Quarry 505 in Central Byfield. Here, the shaft was consolidated by stone packs, and a cartway was diverted around the shaft and collapsed materials. The shaft and cartway were probably already in existence at the time of the roof fall, as the diversion cartway and continuation of apophygate pillars to the west and north of the shaft took place during this early phase of the Allen period (see Case Study 4 in Chapter 12).

In the case of some contemporary roof falls the collapse had been cleared and the material stacked to the sides of barrow-way or cartway routes. Other contemporary roof collapses were completely or partially buried below subsequent deposition of spoil from later quarrying or further falls. Quarrying tools and/or finished stone products had, in some cases, been left in stacking areas waiting for removal to the surface, but were buried by roof collapse before they could be moved.

Only two crowbars from the 19th century were recovered. One of these, discovered during excavating for the modern Stabilisation Scheme, was from below an area of roof collapse in Firs Quarry (2360), and is believed to have been lost during quarrying. The collapse had sealed the quarry floor and the bar with it.

On the floor of the cartway in Quarry 2217 there was evidence for both contemporary and post-quarrying roof collapse. This was a main transport route for the movement of stone products to the surface quarry north of North Road. Flanking stone packs show that the roof required consolidation during the period of quarrying and post-quarrying collapse was noted at the southern end of the cartway (Fig. 10.18). Some 10 m to the north between packs there was evidence that collapsed roof blocks had been broken into smaller pieces and moved on to the edges of the cartway.

In recent years former quarryman Tanky Elms worked as a safety man in Spring Quarry, which involved supporting and safely bringing down weakened roof beds in quarries that were requisitioned for use during WWII. He said that:

> *by tapping the ceiling one could tell how far one could proceed in safety, and avoid a large fall, especially if the ceiling had joints across… If any doubts were entertained about the depth of the ceiling, we'd pick a hole through the lower bed.. insert an iron and tap the bed above to test its strength and then you know whether to pull it down or keep it there and support the lot.* (Hall 1984, 105)

Timber supports

Timber was only rarely used during the early quarrying periods, though lack of survival may account for the general absence of 18th-century supports. During most of the 19th century timber was commonly used for support but it seems that this was largely on an ad hoc basis rather than as part of a systematic procedure.

Timber sprags

Timber sprags (known locally as scorters or scaulters, cleats and props) were most commonly used in 19th- and 20th-century quarrying at Combe Down. Very few timber supports were vertical or horizontal, but were generally positioned diagonally between vertical pillars and roof beds to give localised support. These sprags were placed in small picked notches, ledges or depressions on pillars (probably called 'holes' or 'scorter holes' originally, though termed 'sprag recesses' during the archaeological survey) and angled against potentially loose bed-blocks in the roof, usually at a joint (Fig. 10.19). The effect was to provide some vertical support, but, more effectively, to provide lateral pressure to prevent keystone blocks from dropping out of place. In later quarries large numbers of sprags were used where long spans of major joints were left otherwise unsupported for sawing purposes, or around pillars in Open Rooms where spans were considered large. Evidence of fallen or rotted sprags was noted as a darkish organic residue in the notch or depression that held them. Sprags were sometimes tightened by using redundant iron wedge chips and, probably, thin wood wedges.

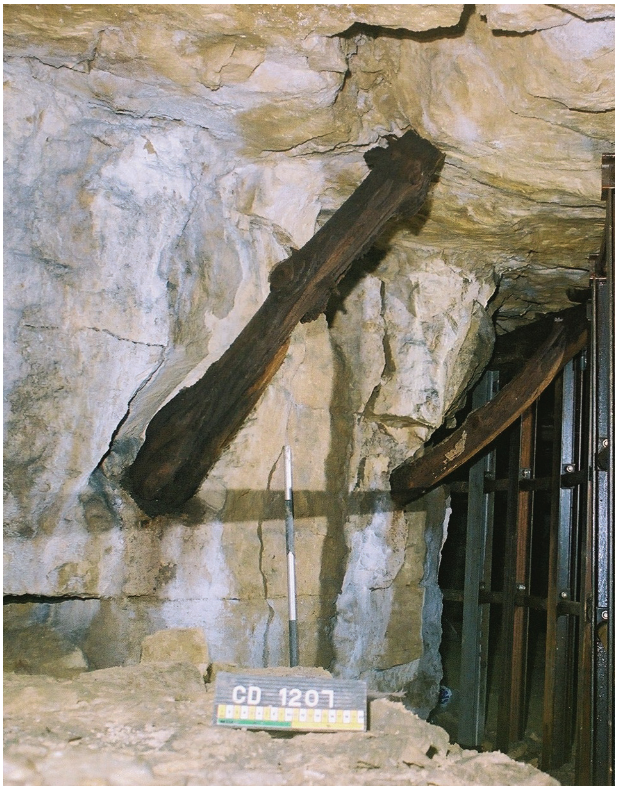

Fig. 10.19 Use of timber sprags for roof support in West Firs (Quarry 2342)

The most frequently observed type of sprags often measured 2-3 m long with various diameters. The sprags varied in number from an isolated sprag, to those employed in pairs, and also to the use of multiple sprags where several were sprung from the same pillar. Quarries 2202, 912 and 2215 often used multiple sprags sprung from a single pillar and more elaborate support mechanisms were employed where main access cartway and railways were in operation. Quarry 912 had one example where the pillar had four timber sprag recesses cut into it to necessitate the support of localised bed separation, with two of the timbers remaining *in situ* on the pillar (Fig. 10.20).

In another example in Quarry 2202 up to nine timber sprag recesses were used for bed support and all nine had fallen to the quarry floor in the intervening 150 years without collapse taking place.

The sprags were held in vertically-backed, square cut recesses. The sprag recesses, cut into the pillar face, were large enough to accept the sprag and were generally well-executed features. The top of the sprag was also held where it engaged the roof bed with a smaller recess which was no more than a small hole and may have been more difficult to access by the quarryman though generally they

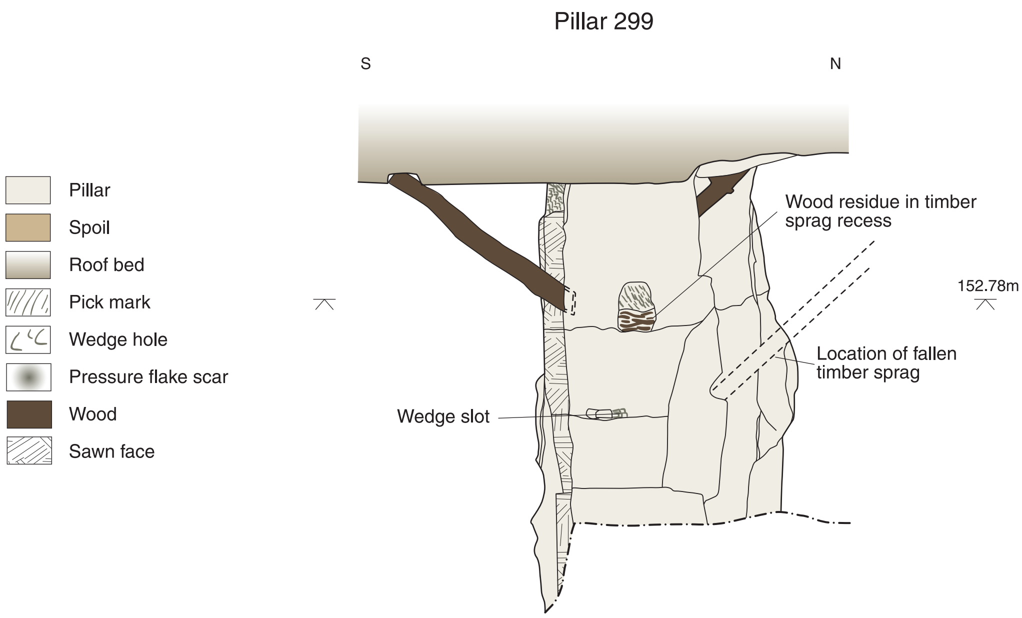

Fig. 10.20 Section of pillar 299, showing timber sprags from pillar supporting the roof

Fig. 10.21 Wooden wedges or cleats inserted to tighten roof blocks

must have been inserted when the face was there still high under the roof for access. There was also a possibility that by extending the recess that it may also have further weakened the block that it was intended to support. The recesses were executed with a 25 mm (1 inch) wide pick at the back of the slot, although a few examples had also been cut with a wider 75 mm or 100 mm bladed hack, and a pick was also largely employed to cut the less well-formed roof recesses.

In a number of the quarries, (the early 19th century Quarry 509 in Byfield being a good example) broken pieces of iron chips were used to tighten up the base of the timber sprags where they meet the sprag recesses so to prevent them from falling from the roof. Several of these were recovered from the timber sprag recesses and this seems to be a particular common quarrying practice. In another quarry in the Firs complex (2342), iron chips were recovered from the roof where several of the timber sprags had subsequently fallen, and where the chips and timber had been calcified together. This practice does not seem to have been used throughout the quarries as chips have not been located on the majority of the timber sprag recesses which were often accessible where the timber had fallen to the ground and only a residue remained. Whether small wooden wedges were alternatively used was not determined. They would generally have rotted so as not to be distinguished from the timber sprag remnants.

Wooden wedges or cleats, often made from softwood, were also used to support the roof-beds and were placed in the cracks between the separating roof blocks so that they would provide some support and help to tighten them where the roof had weakened. They may have provided an early warning of any movement in or of the roof beds, with wedges subsequently falling to the quarry floor. The occurrence was rare in the Firs and Byfield quarries – excepting James Riddle's 20th-century quarry (518) – but common at Shaft Road quarries 2373, 2377 and 2382 and at Foxhill, suggesting it was generally a later practice (Fig. 10.21). In many instances the individual blocks were generally keyed together, but where they had got slightly parted or sounded 'hollow' and had separated from the sedimentary bed above the insertion of the wedge or wedges prevented any of

Fig. 10.22 Horizontal timber used for roof support under Shaft Road.

the blocks from falling. The function was similar to that of sprags and may have been substituted once this was realised.

The placement of horizontal timbers was a slightly more common practice by the end of the 19th century and examples of their use were seen in all the outlying quarries. Timbers were used to support roof beds by wedging them between two pillars or placing them in horizontally cut recesses. Timbers were also used as supporting beams across the entire width of a quarried breach or Long Room or positioned where there was a roof gull and from where smaller rubble and materials that had migrated or that had been washed from the upper geological beds may have fallen. The timbers in these situations were often used in conjunction with other smaller cross timbers. A particularly long example was found at Shaft Road, where it spanned the whole of the room width just under the roof (Fig. 10.22).

Vertical timber props were fairly unusual, with only a few examples, less than a dozen, being noted, some in early 19th-century contexts, though again becoming more common late in the 19th century onwards. Smaller lengths of timber were occasionally noted placed within small jad slots or breaches in the working face to support a single block of stone or give additional support to a roof bed above the slot. Other examples have been used to prop individual weakened or displaced blocks of roof bed including an example sited on the top of a stone pack (Fig. 10.23). Sometimes at the top of the prop or vertical sprag a 'cap' or flat-sided block of timber was placed on top to wedge the timber to the roof or act as a platform. At Mount Pleasant Quarry (2373) in an exceptional example, the roof bed surrounding a collapsed roof had been held with eight or more large diameter props that were fixed into picked recesses in the roof and dug into the quarry floor.

Modern mining engineers have been sceptical of the use of timber supports, considering them ineffective. However, many timbers that still remained *in situ* were particularly solid. On removal for analysis (with modern supplementary support provided) they were found difficult to saw through. The original size was probably more substantial than seen in recent times because of rotting exteriors. The timbers were probably used for a combination of both support and a warning mechanism of ground movement by either squeaking or by splitting. Several sprags were seen to have split under the weight of the settled roof from above within the double height Quarry 512. The inclusion of underground quarries under the mining acts and effective inspection by Mines Inspectors, which was acttive by the late 1880s, may have led to the more systematic timbering seen in the later periods of working.

Steel and iron rail supports

Iron or steel rails were used to support the roof beds at Combe Down in the Foxhill Quarry (2383). The rails had been used in a similar way to horizontal timber sprags but gave a more reliable and permanent support to a poor roof. The three rails were placed across the width of a quarry breach in jad slots between two or more sets of pillars above narrow gauge railways. Three pieces of rail were recorded and each was securely held within two opposing horizontal cut recesses on either side of the room or heading. Two of the rails measured $3^1/_2$ by $3^1/_2$ inches in profile, with the remaining rail $4^1/_2$

Fig. 10.23 Vertical prop placed on a pack

by $4^1/_2$ inches. They were all flat bottomed and had slightly curved and convex upper surface and would have presumably have been re-used from an underground railway that served this area and the other three quarries at Foxhill.

Stone roof supports

Stone arches

Arches have traditionally been used for roof support at mine and quarry entries because of their inherent strength, quick erection and use of onsite, cheap materials, though sawing into voussoirs would add considerably to the expense where they were used. They were not a common occurrence at Combe Down, but two, at the Arched Shaft under Firs Field (Chapter 12, Case Study 9) were part of a spectacular feature, and there were others at both inclined (slope) and level entries in Byfield, and in Firs under the side of and near North Road of a corbelled type. Dome forms as well as simpler barrel vaults were also used to cap shafts, supporting a burden of weak material a few feet overhead. They were also used to support individual pillars. In a stone-using area, arch building would therefore have been a common skill among masons and other stone workers and it is perhaps somewhat surprising they were not used more often given obvious problems with support over cartways. It is possible other arches were built at entries not available for archaeological examination.

The entry incline known as the Irvings Incline in south-west Byfield, Quarry (503) was probably constructed in the early 19th century and was used for access as well as to bring stone to surface. It linked via a sloping area and ramp of mixed fines at its northern limits which appears to have served the high pillar Quarry 503. There is, however some doubt of the actual date, as in the original lease of *c* 1805 (Irving 2005, fig. 7). Access to the same quarry was also provided along an adjacent cartway and through one of three contemporary stone arched entries from Jones Quarry, via what is now Ralph Allen Yard, and it is just possible that the Irvings Incline was constructed slightly later, replacing the earlier entry, as it was not used by the adjacent (surface) quarries as originally anticipated.

The arched Irvings Incline linked the underground quarry workings and an inclined spoil ramp that was used to transport stone blocks to the surface. The incline measures 1.30 m from the roof of the arch to the current floor horizon, is about 3 m wide and 20 m long and inclines at about 1:4. It was built to support an area of poor roof in the vicinity of a large gull located above the central section of the arch and to hold loose stone-blocks and overburden at the mouth of the incline at surface level. It used coursed rubble blocks in the walls, some with sawn and scappled faces, and there was shaped and sawn block in the barrel-shaped arch, apparently placed in a lime mortar. The northernmost extent of the arch was constructed 0.30 m lower than the southern extent so as to go under a lower section of roof where it met an earlier sub-

Fig. 10.24 Stone arch at a West Byfield entry (Quarry 505) with sawn voussoirs

parallel ribbed pillar that remained from earlier 18th-century workings where the incline entered the former underground workings. Later deterioration of the quarry roof conditions, probably after the principle working of the quarry, then necessitated the building of a stone pack at the base of the incline, partially obscuring the original wide access to the incline from the spoil ramp beyond in the quarry workings.

Three other stone arches were also constructed in the southern part of the (Byfield) Jones Quarry at Ralph Allen Yard. where three converging cartways emerge. Because of the use of sawn blocks to create the interlocking voussoirs, they are thought to have been constructed at the same time in the 19th century when the much older cartways were still in use for extracting stone to the surface, but an earlier date is not impossible. All three largely remain buried by post-quarrying surface-derived debris. One arch has been preserved behind a layer of sand, prior to concrete consolidation (Fig 10.24).

This feature was constructed in a quarry located below the Firs Field. The arch was built between two pillars to support the edges of a wide shaft above a cartway that was driven between about 1810 and 1839, as part of the Burgess' Three Acre Quarry (2211). It was approximately 7 m high and about 4.5 m wide. The principal western and eastern faces were constructed of level courses of roughly squared and natural blocks located above the bottom course of voussoirs on the underside of the structure. There were over 150 individual principal voussoirs within the bottom course, arranged in 35 adjacent stones and between three and four blocks deep between the principle western and eastern faces. The majority of the voussoirs had their principle edges fashioned by sawing with only a few blocks having un-sawn faces. The voussoir course had been sprung from either side of the cartway on benches cut into the faces of each of the two pillars. Eight additional courses of sawn and squared blocks were also erected within a fissure or natural joint below the voussoir course on the northernmost pillar.

The shaft was adapted as the main supplies shaft for the Stabilisation Scheme, and a scaled section of the southern face and the underneath of the arch have been included derived from laser scanned data. Concerns there over the roof's stability also led to the space between pillars on the shaft's northern extents having a massive, coursed-rubble pack erected, with other packs constructed on the western edge also.

Six examples of smaller roughly coursed rubble arches have been noted in the northern part of the Firs Quarries (2211 and 2391), constructed to support areas of poor roof where the Twinhoe Beds have been exposed in this part of the quarry. These were located between separate areas of later Bath Stone episodes, and were used to allow quarrymen safe passage beneath areas of collapsing roof bed. The corbelled and rounded arches (Fig. 10.25) were contemporary with several other exceptionally tall stone packs, and all the features were constructed in the vicinity of the Hadley Arms.

The stone arches were integrated within and located at the bases of the much larger stone packs constructed of smaller rubble and material derived probably from the collapsed Twinhoe Beds at the roof level. The packs range in height between 4 m and 7.5 m and were roughly coursed throughout, with rubble blocks within each of the successive courses being slightly stepped out from the course below to form either the corbelled arched openings and/or the rough barrel-shaped vaulting. The arches contain no specifically cut or shaped voussoir key stones and had been predominantly constructed out of naturally derived rubble. One of these covered what were known generally as the Hadley Arms Steps (Fig. 7.11), though the steps appear to predate both the arch and the Public House. They may be associated with contemporary quarrying in the area as part of the Three Acre Quarry, or more likely, associated with a quarry located to the north of North Road. This operated prior to 1850, and again from the 1870s (under G. Mann) and into the early 1900s. Graffiti of 1887 and 1888 found within this area may be contemporary

Fig. 10.25 Rounded arch 4142 in Central Firs (Quarry 2391) under North Road, probably dating to the early-mid 19th century

with the corbelled arches and stone packs and Quarry 2391. The larger and taller stone packs are not thought to be part of this quarrying and may be part of the later consolidation of the Turnpike Road located above this part of the quarry, now the North Road.

Roof support packs

Packs in general were the most common means of roof support, other than timber sprags, and provided a more permanent support than timber. However, the stone packs were used to a greater extent to support, retain and to store spoil, and this is considered in greater detail in the section on spoil management below.

Roof collapse threatened serious adverse impact on quarrying, access and transport within and beyond the directly affected area. The principal working areas, transport routes (including barrow-ways and cartways) and access points located at the junction between underground and surface quarries were more robustly supported than other areas. In these locations additional consolidation and support was provided by flanking stone packs along cartways, stone arches and/or more numerous timber sprags. The principal transport routes were well-maintained and it was likely that smaller roof collapses would have been quickly cleared.

Roof supporting packs do not appear to have been routinely constructed as work progressed, but seemed to only occur in locations where the roof was specifically considered to need supporting or where localised collapses had already occurred and additional support was needed. Many were probably largely built to safeguard the quarryman during the period of extraction and though leases of the early 19th century placed a duty on the quarry-master to (permanently) safeguard the surface, in the main this seems largely to have been only observed where there was a highway or buildings or for a cartway or barrow-way route, in addition to at the quarry mouth where future safe access was required.

Where the packs were used to support the roof they were generally vertical in form, which increased the load supporting capabilities in comparison to an ordinary rubble pack that had a battered profile. They were generally also constructed of better selected materials that included larger blocks as well as rubble. Some of this material derived from beds of poor weathering quality, such as the picking beds or the overlying Twinhoe Beds where there had been a collapse, and some was sawn or roughly squared blocks that had been discarded after a flaw was discovered. But in some locations the quantity used was so great, and of so good an apparent quality, that it was clearly stone that otherwise would have been marketed and thus had an economic cost above that of the labour exerted in its movement.

Depending on the location, the packs were built single-faced against banks or solid rock, or double-faced where they had to stand independently, with coursed rubble or block facing around a filling, if especially massive, of carefully placed rubble, or tipped-in rubble if less so. The stone packs were also occasionally used in combination with timber sprags, as noted earlier.

The majority of the longer or larger supporting packs are thought to be contemporary with 19th-century workings, or in those areas and especially along those routes attributable to the 18th century that were still required for the transport to the surface. Since time appears to be a major factor in the progressive collapse which took place, it is likely that some newer sections of cartways, often virtually if not entirely abandoned by the mid century, never needed such substantial support, though, as seen above, in the use of arches and heavy stone packs, the large scale and generally higher workings in the Three Acre Quarry and adjacent quarries were very heavily supported.

Reinforcement of old cartways

The roof support packs in older areas were principally west of The Avenue in the Allen and Allen Estate (Phase II and III) areas, Quarry 2201 for example, where cartway development was fairly continuous through them, the packs largely being built between the pillars. East of the Long Drung, roof support packs, notably along the Brow cartway appear generally to have been contemporary with the 18th-century working, and were nearly continuous over substantial sections in front of the pillars. Otherwise only short lengths of stone packs were seen during the survey although they flanked much of the length of visible cartways. They were well-constructed with fairly regular courses built from blockstone, and extended from the quarry floor at cartway level to the roof (Fig 10.26).

The northern extent of the most western of the two Allen cartways in Quarry (505), roughly under the old telephone exchange (now a church) on Combe Road, seems to have had pronounced instability in the late 18th century, preventing its continuance around 1804 though this was originally envisaged in the lease. Here the roof at worst is only a metre or so below the surface, and to safely stabilize the end section a 3 m-high vertical pack has been built on the north eastern side in very short sections, stabilizing a section of roof bed and a localised slipped block of stone that protruded from the roof bed, before the next section was emplaced: this has left vertical gaps of unevenness in the pack.

The eastern of the two cartways in Quarry 505 did remain in use and short lengths of pack assisted the arched support near the entrance. It required substantial reinforcing of the roof around the first of the wide shafts on it, adjacent to which a substantial roof fall had caused the original cartway route to be diverted. A sub-circular rubble pack had been built around the base to consolidate the lip and the shaft

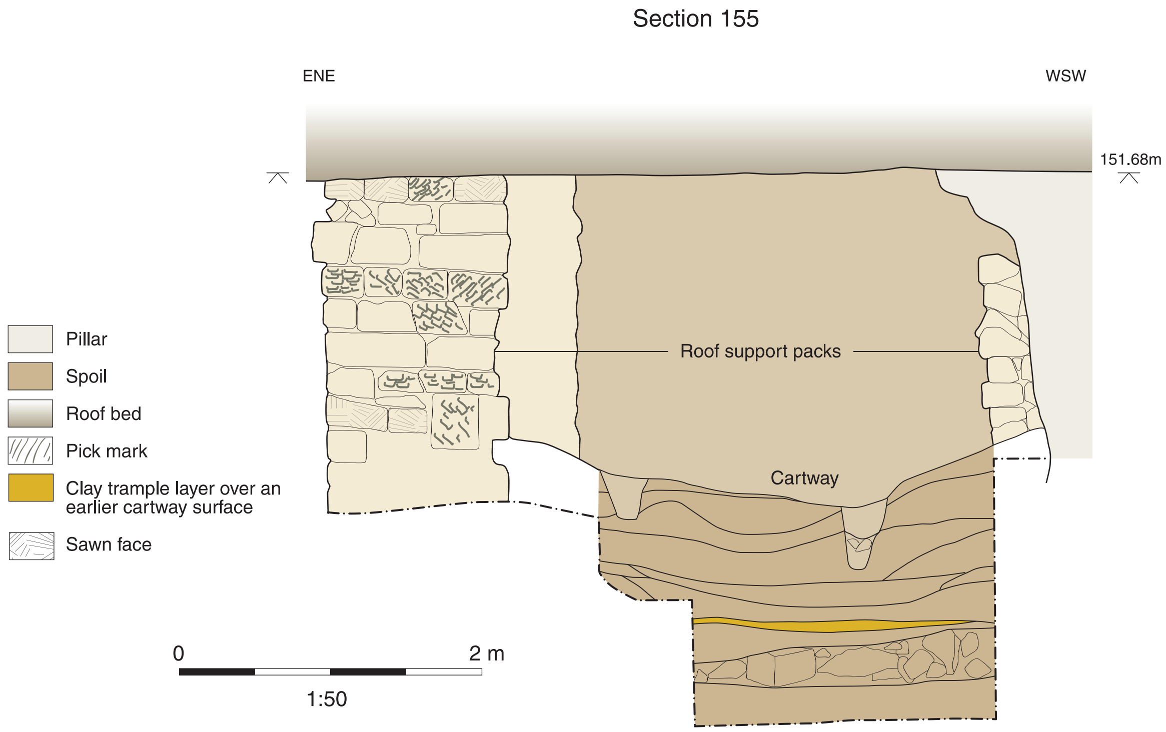

Fig. 10.26 Section showing roof-support packs alongside cartway (Section 155) in the easternmost cartway east of the Long Drung

had been filled. The pack was constructed over the remains of the roof collapse around the shaft and contained large blocks of collapsed roof materials within the first four or five roughly placed courses for approximately the first metre lift. The upper metre of the pack used rubble stone that contained some scappled blocks and re-used smaller roof collapse material.

A similar but much more substantial sequence of consolidation took place along the two principle older cartway routes and the eastern branch from them in Central Firs driven northwards from Sheeps House Quarry. The first 50 m-extents of both routes from close to the quarry entries were supported on either side by (early to mid) 19th-century flanking support packs (Fig. 10.27). In the eastern route, this had followed either roof collapse or deliberate stripping out of the roof between the apophygate pillars, leaving only residual features. In the western route the roof conditions were particularly bad despite the heavy support by provided by regular-coursed stone blocks. The branch cartway over which a large fall separated it by the 19th century from its more distant section, was adapted to link to the mid 19th-century Quarry 2202. Again the roof was stripped out, or had previously fallen, and a floor-to-roof pack of massive stone and rubble 1 m thick and some 4 to 4.5 m high had been built for some 15 m along the northern side. The two main cartways further in seem to have required much less support, possibly because they were not reliant there on apophygate pillars.

19th-century working roof support packs

In Firs Quarry 2217, north of North Road near Farrs Lane, a 19th-century cartway had been supported on either sides of the route by five individual segments of stone pack which were in places built into the voids of an already partially collapsed roof. They measured up to 15 m in length, with an average width of 2.20 m, and were built from the floor to a height of 3.70 m. The materials used with the construction were generally stone rubble and small blocks up to 0.95 m x 0.14 m, some of which had scappled faces. A stone pack, also incorporating several large fallen roof bed blocks in its construction, had one block measuring 1.60 m length and 0.90 m wide built into the pack 3 m above the cartway surface – a testament to the ingenuity and determination of the quarrymen. Smaller roof falls had been broken up and stacked alongside the cartway, but a larger collapse in between the packs finally made the cartway inaccessible.

The south edge of North Road near the Hadley Arms Quarry (2211) was supported by a 110 m length of roof support packs (Fig. 10.28). The pack was constructed generally 4-5 m high, utilizing block and rubble stone of good quality, including scappled and sawn blocks. Several arch forms were built into the pack, as noted earlier. The wall is believed to have continued to the west, following the same alignment, where a similarly constructed wall was seen in Quarries 2212 and 2216, and in places was used to retain spoil on the northern

Fig. 10.27 Flanking roof support packs in the first section of Allen's west cartway from Sheeps House Quarry

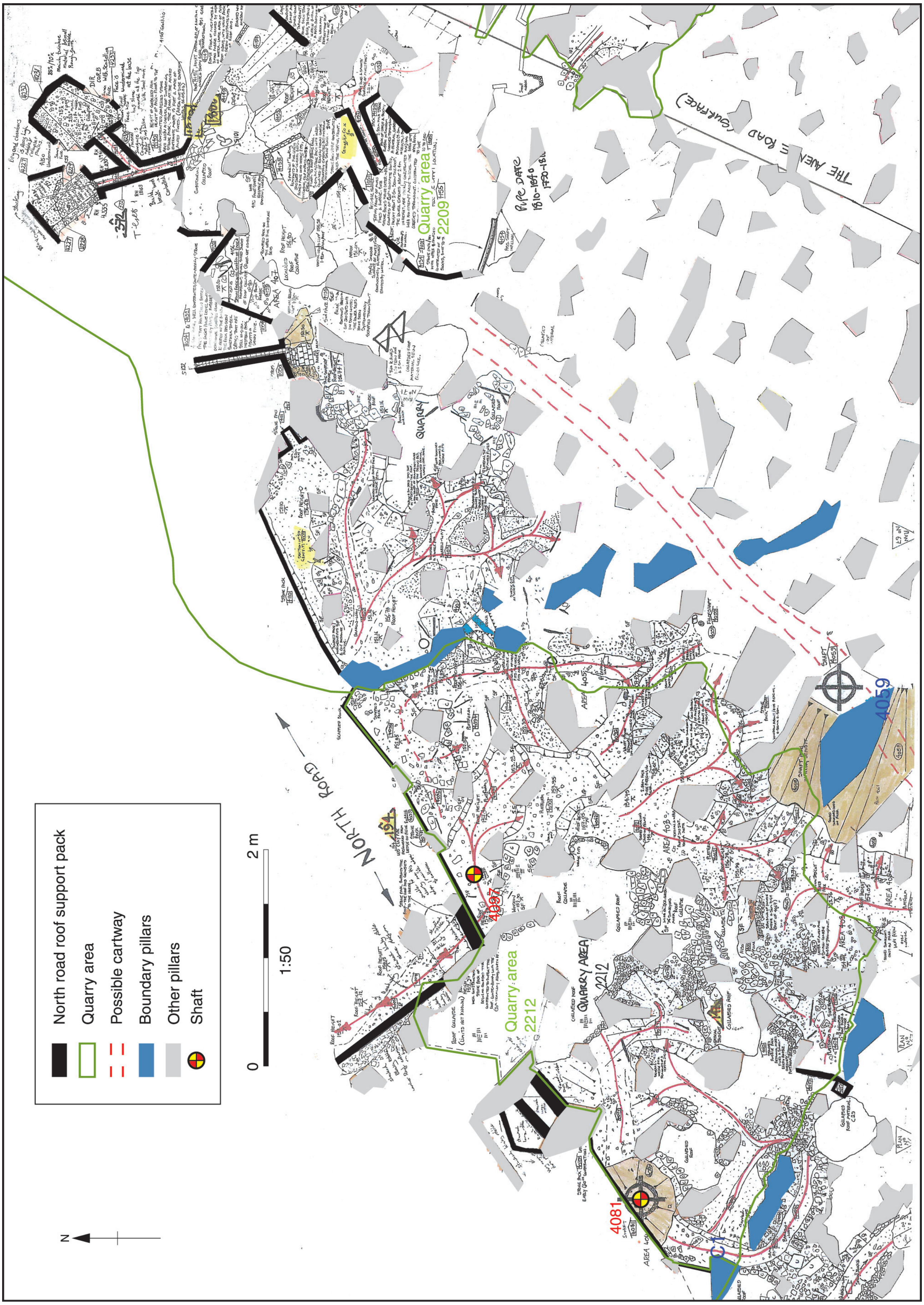

Fig. 10.28 Plan of the North Road roof support pack

Fig. 10.29 Bathite blocks used to support roof under the rear of the Hadley Arms

edge, below the North Road. All the segments of the walls are believed to be contemporary and were part of the consolidation of the former Turnpike Road when it was strengthened to accept tramway traffic in the early 20th century.

An unusual use of materials within the same Quarry (2211) was a stone pack located to the south-west of the Hadley Arms, constructed to consolidate and retain the backfilled surface-derived materials in one of the former extraction shafts. It also provided a room underneath the Public House for entertainment in the 1980s (Hadley Arms landlord pers. comm.). The lower courses utilised stone from the quarry whereas the upper courses used discarded 'Bathite' blocks, a faced concrete block made by Tarmac at Mount Pleasant Quarry in the 1970s (Fig. 10.29).

East of the Long Drung are examples of well-constructed stone packs, in regular courses using roughly squared blockstone and some rubble. These were built under a house to give support to the foundations. Several other instances of pack building occurred in this area which feasibly had the same main purpose.

Stone walls

The distinction during the underground survey between stone walls and stone packs lay in their construction, and the use of bonding materials such as lime mortar or cement. The two types of construction were generally built of similar materials, although the walls often had better constructed courses and more carefully chosen and more regular blocks. The structures were generally placed where the roof was poorly supported and which needed the additional integral strength that a wall bonded with lime mortars (or cement mortar in the 20th century), provides. They were generally located along the edges of the cartway or railway routes at the mouth of the quarry entries. The vast majority of the mortar bonds were consistent throughout the recorded quarries, and consisted of a weak mid gray, lime mortar with few visible inclusions.

Several such walls were used to seal up the mouths of the former quarry workings where they were no longer used for access. This type of wall can be seen within the Firs quarry mouths at the southern extent of the former Allen cartways at the open Sheeps House Quarry (Quarrymans Court). The walls were constructed with rubble stone and thinner material from fallen roof beds. More recent blockages have used concrete blocks.

Conical packs

Small stone packs within the open areas of the rooms between the pillars were occasionally built, with perhaps a dozen examples found. Most were square or rectangular in plan but two examples were conical in structure. One located in Firs Quarry (2203) was constructed next to two other stone pack roof supports (Fig. 10.30). It was built to a height of 2.30 m and supported an area of roof that (unusually) had been previously supported by vertical timber props, which had failed. The other, located in Byfield Quarry (514), was noted previously by David Pollard during his 1994 survey (Pollard, 1994, 86).

Chocks

The simplest form of chock was either a timber or stone block used to prop a roof bed or individual roof block. They were only rarely found, but were occasionally used on top of packs or on top of spoil heaps built close to the roof to close the gap under the roof. Another form of stone chocks, also referred as cogging or cribbs, were constructed of selected blocks of stone that were placed in position to form a more solid mass. The area near the Hadley Arms

Fig. 10.30 Conical pack in East Firs (Quarry 2364)

close to the North Road included chocks that were either stacked singularly or in combination with other stones placed within a few feet of each other. Stone chocks were placed against the roof above rooms filled with spoil and were sometimes tightened with small timber wedges. Some spoil-filled rooms had a series of rectangular cribs built with rubble stone walls, perhaps a metre across and placed one after another to fill the whole space back to solid rock, and were filled with rubble, from floor to roof. The multiple walls gave much more resistance to crushing than a standard roof support pack. Some of the features at North Road, may however, be post-quarrying, designed to support the road.

Fig. 10.31 Sawn stone used as a sprag in West Firs (Quarry 2342)

Another type of chock was a variant of the sprag, with the insertion of an individual block placed at an angle or near-vertically. Two examples of this type of support have been seen within the Firs quarry complex. That from Quarry 2342 was a sawn stone support measuring 850 mm x 200 mm x 113 mm in blockstone, which had been sprung from a pillar face into the roof. A sawn block in Quarry 2211 was placed on the southern side of the cartway to support a failing roof block (Fig. 10.31).

Support value of all packs and spoil

With relatively high and narrow pillars and often their wide spacing, had the Combe Down Quarries been largely emptied of spoil, then it is fairly certain the whole complex would have suffered severe 'domino-type' collapses affecting much of the surface. In the few full-height pillars seen, up to 8.5 m, the pillars can be seen to be riven with a series of joints little more than a foot apart. These have opened slightly and collapse was likely within a relatively few years or decades. That this did not happen was due to two important factors. First, that all spoil as well as artificial features assisted in providing lateral support, so that the bed blocks of stone forming the pillars could not normally be forced sufficiently out of position for the pillar to collapse. Second, because the top of the spoil was frequently close to the roof, any collapse of the roof, typically bed-by-bed due to delamination, could only be for a relatively small distance, as the void which developed above the fall 'bulked-up'. Any void would soon be filled by progressive collapse preventing upwards migration and crown holing.

Disposal of the waste

Spoil

This is the general term for the economically unwanted material, otherwise termed discard or waste, 'gob' or 'deads', which was produced during the production of saleable stone. It could be material which was found with the stone, such as clayey material in fissures, stone of low quality, for instance a poor weathering stone, or was too fractured or contained cockles (calcitic vugs), or had been broken in the process of quarrying or squaring of blocks, or coursed rubble. At Combe Down, something like 40% of the total amount of quarried material was discarded as spoil, occupying somewhat over half of the excavated space. Most of it was oolitic limestone from the quarried beds. The proportion was probably higher in the earlier periods and less in the later. Its disposal or dumping was a major problem, both for the expenditure of effort and for leaving sufficient space to effectively continue working. It is clear that a great deal of consideration was given to spoil disposal, and working methods evolved first to reduce it to a minimum and secondly to stow it in suitable places with maximum efficiency. However, a great deal of spoil was not carefully disposed of and this led in part to the apparently disorganised appearance of both spoil heaps and the general underground landscape.

Sources of spoil and developments towards its reduction

Once the quarry had developed, the first source of spoil was encountered just beneath the roof level, the picking bed. It was just under a metre thick and of soft and poor weathering quality, not generally saleable by reputable quarrymen. In the earlier quarries this was totally removed and most discarded – amounting to some 20% of the total excavated material – although some may have gone for interior walls of buildings where weathering was not a factor. This proportion was vastly reduced with the use of the different forms of jad slots and especially of the regular parallel-faced jad used to undercut the roof. The use of the parallel-faced jad below the roof negated the necessity to remove the picking beds, and in consequence reduced the spoil produced to perhaps about a half or third the former. This spoil was all produced at a high level in the workings and ideally was kept at and disposed of at that level. This may not have been easily possible with the simple method of working by pillar and room before the mid-late 18th century, but the development of Long Rooms, with their high level windows and Long Wall, pillar and room systems with planks to cross the gullet, meant this became feasible. The elaborate barrow-way systems seen around the Grand Canyon (2209) allowed spoil at different levels to be taken for considerable distances without losing significant height (see Chapter 12, Case Study 9).

Individual beds between pillars were freed in a similar way, but vertically by opening out a joint or by breaking one of the less valuable bed-blocks or wrist stones. Stone was inevitably broken as bed-blocks were extracted. Because the cross joints were not at right angles, there was further waste at pillar faces and joint intersections, and some beds, because of lateral variation in the deposit, were probably of little use either because of quality, thinness or presence of vugs or cockles. Finally the stone had to be squared from the usual diamond shaped bed-blocks, roughly in the case of production for coursed rubble, more accurately by scappling for blockstone. These losses probably produced the bulk of spoil. The remainder was from joint or gull infillings, notably clayey material or small stone from close jointing, or fracturing from rock movements, and from erosion derived by water draining down and from roof falls migrating into the beds over the freestone. There was some scope for reduction of some of this wasted material. Use of lines of wedges and chips for breaking and, above all, the use of saws resulted in the amounts of spoil again being moderately reduced. By taking more beds from below, maximizing the take of stone up to the 8.5 m depth seen in one or two areas, then the proportion of waste or spoil again fell. Further spoil came from the banker mason activity in some areas in which blockstone was worked into wrought stone or items such as ridges, mullions and other decorative or ornamental work.

This wide range of origin produced many types of spoil. There was plenty of stone of block size, some from overlying dropped beds such as the ragstone or bastard stone, with much not obviously different from material being sent out, except perhaps being somewhat more misshapen. Indeed it is difficult to see why much of it was not broken to produce coursed rubble for building. Perhaps this was somewhat reserved for thinner beds of good quality, despite occasional comments about the willingness to supply poor stone given the opportunity. Stone was, of course in plentiful supply and any losses were those of the master rather than the workmen, so the apparently good quality stone seen in the better quality packs may sometimes have been chosen for the ease of workmen rather than using the misshapen real waste material. Fragments of rubble size, below about 500 mm to some 50 mm, and small rubble for lumps below this were the most common, but there were very substantial quantities of fines, below about 5mm, typically produced by pickwork or banker mason activity. Often these different sizes could be separately dumped, with advantages, for instance of better barrow-ways and cartways.

It is clear, from the patterns of spoil, that organised systems of dumping evolved, both in the design of the working methods, and down to the actual individual dumping of the barrow-load. The disposal of the spoil was thus an important part of the quarrying process. It was visible in the large number of barrow-ways at different levels, in the 'windows' found at picking bed level through which spoil was dumped, and in the tactics adopted, presumably to minimise effort, to stow and stack the spoil in an organised fashion. This resulted in common features such as lateral dumps alongside barrow-ways, packs supporting large banks of waste and gently rising banks and inclined barrow-ways leading to arcuate tipping fronts. Because of the need to use wheelbarrows, spoil disposal almost certainly had an effect on the height of roof above the floor, either over about 1.8 m (full height walking) or somewhat below this at about 1.4 m (crouched walking) near the final disposal area. An indication in the reduction of amounts of spoil was provided by the higher roofs over dumps in some of the later quarrying areas, though this was difficult to assess as almost everywhere around them by this time had already been worked and there was no need to keep any but the most direct required access ways open.

The initial opening out of a new quarrying area generated large amounts of spoil which had to be removed from that area to provide working space. In an established working this was dumped into other adjacent worked-out quarrying areas. Many of the longer-than-average barrow-ways were seen to be related to this initial excavation, and were essential to the opening-out process. An example is Quarry 503 in Byfield, where the abundant fines produced by the jad cuts and slots in the high pillar area were dumped in the adjacent older workings on the north side. The fines were dumped to within a few tens of centimetres from the roof, partly by 'shooting' it over the end of the barrow, after which rubble was thrown-up by hand to the roof level (Fig. 10.32). This dumping continued so as not to intrude on the open, worked-out areas to maintain handling space before its eventual abandonment.

The most constant feature throughout the quarries for dumping involved the development of cartways and other access ways to just behind the front of the face on top of a bank of spoil, which was kept just behind the working face as it advanced. This formed a working floor at the end of the cartway where stone could be scappled and stored prior to carting away. Initially the floor of the cartway was some 2.5 m below the roof or ceiling, found in many areas of the unaltered original Allen cartways with up to some 2.5 m of spoil under the working floor. The higher space in later cartways perhaps reflected a greater depth of beds extracted, but the key reason was probably to place the carts or waggons next to the prime freestone bed for ease of loading. Greater depth, however would allow a similar quantity of waste to be stored in the cartway as previously. The spoil dumped as the face moved forward allowed the low front or gullet (below cartway level) to be cleaned up with minimum effort and any shortage of material for this was easily made up by material from higher-up. This probably included finer material, which was used to produce a good surface for the cartway. This specific use suggests such material was often stored or kept in specific dumps to be available for this purpose, rather than being dumped indiscriminately with other sizes.

Fig. 10.32 Miner seated in original position demonstrating waste-stowing to roof level

Due to lack of archaeological access to full working sections, it was generally only possible to hypothesise about dumping of other spoil in the early phases of working. At the upper levels, visible in workings alongside cartways, for example in the western Allen cartway from Jones Quarry 505, the spoil was dumped in low banks alongside the cartway and was covered with fine dusty material. This was clearly ground stone slurry scraped off the cartway, implying its replacement by good fines as a routine and a degree of cartway or roadway maintenance. On this, or built off the floor were low rubble packs behind which spoil had been stacked almost to roof level in places, in the form of irregular humps. The material below was not visible but modern roadways which cut through such banks revealed repeated sequences of barrow-ways overlain by layers of spoil. It is reasonable to think this probably meant a fairly orderly system of barrowing from different levels as the working face moved away, with final dumping either by 'shooting the barrow' over its front, or by hand shovelling or throwing-up. Perhaps because of the use of jad slots and less spoil in the adjacent parts, the top surface had long heaps of rubble and fines between barrow-ways, with a good height for barrowing, though the heaps between the barrow-ways were piled to within a metre or so of the roof.

It seems likely that a system evolved in the development of side rooms for dumping spoil. At the base of the sequence was the floor formed behind the gullet. On top of this was dumped material, which could not be accommodated at the subsequent current working area. Finally, spoil from the picking bed was dumped through 'windows' at the highest level, opened into the worked-out earlier room alongside. Direct evidence of these windows had largely gone with the removal of the lower beds, but they were sufficiently frequent in almost all areas to suggest this function, probably as well as improved ventilation and access. This dumping process was not completely exposed in any archaeological sections as rooms of deposited spoil were usually only partially exposed by the Stabilisation Scheme, but the hypothesis explains features seen in different areas, notably within the Gullet workings in Quarry Areas 102, 201, 302 and 305. This hypothetical sequence was initially understood from observations of the Long Room system, where in Quarry 2201 material dumped through windows was visible lying on roughly levelled spoil overlying the top of a former cartway floor (see Figure 8.10).

In what became the most extensive working method – the Longwall with gullet and pillars – most spoil was, after the initial phase, dumped behind the long gullet (see Figure 8.11) first at the working floor level at the gullet, then behind a low rubble pack to a height 1.8 -2 m below the roof, (thereby leaving a useful walking height). Finally, dumping from a high level using barrow-ways and possibly planks across the gullet took place. Examples of suitable planks were found, but not *in situ*. Subsequent dumping from this or other quarry and secondary dumping often reduced this height to around 1.4-1.6 m, the likely but uncomfortable height needed for barrowing with a bent back, and in some areas dumping was done up to roof level. Figure 10.32 shows a modern miner seated in an surviving original position demonstrating how material would have been handed up and stowed at the back to roof level.

The first typical roof height of about 1.6 to 1.8 m provided a useful walking height behind a barrow, sufficient to allow both tipping over the side of the barrow on the margin of heaps, or projecting the spoil forward over the front end. There was certain evidence only of the builders'-type barrow at Combe Down, which could be used for either purpose. Such a barrow would, though, be difficult to use in low-roof areas, and a modified form of barrow with low rear legs may have been used, or no barrow at all. In many mines a mine barrow with a body slung below the 'styles' was used, its base sitting on the floor, and something similar may have been used in difficult conditions at Combe Down, and the mine barrow was certainly used in the Wiltshire Quarries (Derek Hawkins, pers. comm.).

Always subject to individual idiosyncrasy, spoil heaps developed in many ways, but several

Fig. 10.33 Inclined barrow-way

common types evolved. Those recorded were all at upper levels in the dumping sequence, but it is likely that similar methods of easy dumping at the top resembled those lower down, which were subsequently buried.

Either the barrow-way was developed on top of an existing bank or, especially in high workings where space allowed, a single barrow-way, inclined as necessary, was developed out of the working area at grades typically between 1:4 and 1:6 (Fig. 10.33). To achieve this spoil was dumped over the front of the barrow to form a tongue ahead, with coarse lumps thrown to the side. Fines seemed to have been selected to form the surface for the wheel to run easily.

Once within the dumping areas, along the barrow-ways as they passed through worked-out rooms, two types of dumping applied, the first perhaps where large amounts remained to be disposed of. Lobate tipping developed a narrow gentle incline or ramp to the furthest point, providing a good barrow-way surface as the incline pushed forward – typically of fines dumped and graded over a rubble base. Dumping subsequently took place laterally over the side of the barrow (always the easier mode of tipping) along the sides of the gentle incline, either as it was formed, or subsequently, preserving a level or sloping surface with the barrow-way at the higher level. The supply of materials, notably of fines for the surface, possibly decided this. The second method may have applied only in the final stages, with lateral dumping alongside the barrow-way so the barrow-way was then below the level of the dumps. Sometimes this was carefully done back to the pillars to maximize use of space, sometimes only immediately adjacent to the barrow-way itself. At the end of the run, spoil was similarly dumped and, in many cases, rubble or fines thrown up to just under the roof. Shrinkage seems often to have left a small gap under the roof – if not, deliberate stacking or packing of material to roof might be suspected.

Lobate dumps were often found in either wide areas or in a long linear sequence of rooms. In other cases the tipping took place on a wide front, across rooms, with a distributary system of barrow-ways (see Chapter 12, Case Study 9). These were developed similarly to the above but along the 'dumping-margin' a series of ever-widening arcuate fronts were developed, with the barrow-loads clearly having been run around the near circular front tipping over the edge, until the margins of the area were reached. A highly developed sequence of this type was found south of the Grand Canyon (Fig. 10.34). It may be more suited to dumps where there was a high proportion of fine material, allowing a good surface over the whole of the dump.

Roof heights requiring a severely bent back suggest a local shortage of dumping space. Spoil in such passages and rooms seemed often to have been stacked at one side, leaving just space for the barrow before final filling of the remaining space to 0.80 to 1 m or so from the roof. Wheel marks were sometimes visible in fines and rubble at the side where the next load was dumped. In many cases rubble stone had finally been thrown up on to the top of the earlier mixed fines and rubble and stacked rubble.

The first stage in many sequences seen seems to have been dumping by roughly stacking rubble at one or both sides, placed so as to keep the barrow-way clear. Then the barrows were dumped over-

Fig. 10.34 Lobate tipping in Central Firs south of the Grand Canyon (Quarry Area 2209)

the-front at the end and often rubble thrown up over it to the roof, with a gradual withdrawing from the filled area. Sometimes where space was less critical the withdrawal phase took the form of a series of ramp-dumps along the barrow-way, like a series of slightly inclined long steps. In proximity to boundaries, and especially near cartways where space was retained in the adjacent worked-out side-rooms, substantial rubble-stone packs were built to hold spoil back.

As the amount of spoil diminished with improved working methods, new forms of dumping were used once space was established, presumably with the object of providing more space in the working area as well as reducing the distances of travel for dumping. In some cases this was by placing spoil behind large, carefully-built rubble-packs, in others by dumping to form level platforms in a series of broad steps or platforms with short ramps between. A notable example of the first was seem lining the cartway between Firs Shaft and the Hadley Arms, with a wide space created (for storage?) on one side of the cartway, and beyond and on the other side high rubble packs to the roof holding back spoil. In some cases whole areas were apparently devoted to spoil. South of Stonehouse Lane, the gap on Hawkins (1994) map between the modern Firs and Byfield Mines was almost totally infilled with floor-to-roof spoil. The quarrying area 2397 appears to have been worked in advance of the workings on either side, owned by different concerns and used by them both as their dump. There was no provision for this in the leases soon after 1800, but either the landlord had permitted it on the basis that it provided support for the surface or the two leaseholders worked systematically in conjunction with each other. A similar walled-off dumping area (2395) appeared to be under the Long Drung in East Firs, and, indeed, much of Far East Firs was packed with spoil in this way, though that may be a consequence of small-scale, low-height working.

Open Room quarrying in the latter part of the 19th and the early 20th century developed another form of spoil disposal. This may have been partly possible because all adjacent areas offered space to allow the working area to form a flat space at cartway level between three or more rows of pillars. When this space was no longer required for the working floor it could be more systematically filled. Examples were seen in James Riddle's quarry (518), and also in what was probably Stennards Quarry 2367 south east of Farrs Lane south of the Turnpike, both late-stage working . These took the form of a series of broad flat-topped platforms linked by ramps. Neither was very large, partly because the quarries themselves were small, partly because they were only involved with the last stage of the working.

The overall impression formed from the archaeological investigation is of generally carefully considered strategies for spoil disposal minimising the effort required to dispose of anticipated necessary amounts in older working areas, with disposal clearly preferred immediately adjacent to the working face. These strategies were modified by those who actually carried it out. Particularly where there was no pressure on dumping space, in perhaps the last stages of operations, which are what were left for recording, a less disciplined form of dumping may have prevailed, leaving the apparent chaos observed by modern investigations as the over-riding characteristic.

Spoil as evidence of associated activities

The study of barrow-ways and spoil dumps developed into one of the most fascinating aspects of the workings. It was one of the best indicators of the sequencing and can even allow deduction of dates or phases of working. The spoil itself carries evidence of the methods of working employed in given areas, and the type of spoil could sometimes reveal its origins and, sometimes, secondary activities. Examples include use of jad cuts in Quarry 503 and dressing or bankers' waste in Quarry 2347 (see Working floors in Chapter 8). In two cases greyish clay related to wells sunk to the Fullers Earth below. Openings into the quarries – shafts and side entries from surface quarries – had waste with a patina subtly different from that derived from underground. Dumped rubbish was even more distinctive.

There was an obvious stratigraphic relationship in dumping since it could only take place in an earlier worked-out area. Whereas the source area was often totally concealed, barrow-ways leading from it to dumps indicated the concealed area was newer. In many areas it was possible to plot these relationships, which were shown on the site archaeological plans with arrows. These confirmed earlier and later relationships with pillar forms, for example, thus allowing broad phasing of the workings and sometimes close dating in the relationship with a well-dated areas known from leases or other documentation.

The use of packs for spoil stowage

Stone packs were one of the more common quarrying features. They were located throughout the Byfield and Firs quarry complexes and within outlying quarries. They were used to support the roof and to retain waste stone discards. Their use for roof support has been considered above, and it is their use for stowage of spoil which is considered here.

In quarries, the ability to build packs – drystone walls if used at surface – was a skill most labourers, let alone skilled quarrymen would possess to some degree. Only substantial packs and arches would require skilled supervision. It was therefore useful to discern the original intent in order to differentiate between stacking and packing.

The stone pack was self-supporting and able to withstand pressure from spoil dumped behind it, or to support a roof sometimes to heights of several metres or even higher in specialized applications such as at the Arched Shaft under Firs Field. It was normally carefully built with placed, often coursed block or rubble stones, following a regular line and with a plane front. It was often battered slightly, to better withstand pressure. Stacked rubble was defined principally by function and capable often of only supporting its own mass. Usually, however, the stones were unevenly placed and the front irregular. Stacks were fairly low and typically rather carelessly placed, the only requirement being to ensure they did not fall back on to a barrow-way. Lateral dumps of rubble alongside barrow-ways were often slightly 'tidied' by stacking the front to keep the barrow-way open. Stacked dumps were found throughout, whereas packs were generally located with a distinct purpose, lining cartways, laterally supporting pillars or holding back substantial banks of spoil. When reinforced by mortar, as next to entrances or, in one case, for support under a main sewer, they have been distinguished as walls.

The stone packs and walls were generally recorded as solid black rectangular areas during the Hawkins survey in 1994. These were generally fairly accurate in both their orientation and extent and were used as general baselines in the archaeological survey. They were adapted to illustrate each of the structures individual facets and their relationships with other quarrying features in the landscape.

Stone packs were regularly used alongside cartways and the more permanent barrow-ways to provide support for the spoil discarded beyond. They were either built-up in advance, so that dumping could take place against them from the rear side or, more commonly raised as material was dumped over or on top of them, using selected pieces of the dumped rubble or block in their construction. Notable packs lined the Firs Shaft-Hadley Arms cartway (2211), and the Grand Canyon (2209) which branched from it, had packs over 4 m high placed between pillars (thus giving them support too), and built-up in a few places to within a metre or so of the 8.5 m high roof. Some packs had a dual or triple function – to support spoil banks and the roof, and even to laterally support pillars.

Small packs were used to hold back spoil behind the gullet, one pack succeeding the next as the face advanced. They formed loading bays or walls and, at Shaft Road for example, to build a platform on which a crane base-stone was placed. In Far East Firs a small pack formed a base for a saw-sharpening stone bench. They also protected wells, built either from inside the well, or from within the quarry workings. In one case a pack was built like a helter-skelter around the well, to allow climbing up to place the top stones.