The maximum depths attainable by hammer drilling vary widely under different conditions. The chief limiting factor is the hardness of the rock drilled, since this property controls the loss of gage in drilling. At some mines where the rock is extremely siliceous and hard holes 50 feet deep can rarely be drilled, while at other properties in favorable ground, such as that afforded by limestones, remarkable depths have been reached with hammer drills. The 272-foot hole already mentioned is the deepest one of which a fairly thorough search of the literature has revealed any published record, although a 300-foot hole[85] was confidently planned at the Tonopah-Belmont in 1926; no record of the success of this hole was noted in the literature.

DIFFICULTIES IN OPERATION

Some operators have been dissatisfied with deep-drilling results because loss of gage prevented the attainment of the depths desired. In many cases such results are unavoidable, but often they are due to lack of familiarity with the equipment and an imperfect conception of the results that can be achieved by the machine in the hands of a skillful runner. Loss of gage may in some instances be largely offset by following dulled bits with sharp ones of the same gage and carefully reaming the hole. Investigation of the steel sharpening and treatment may reveal the possibility of prolonging the usefulness of each bit. Stellited bits[86] for this service have been employed at Anaconda and elsewhere, with gratifying results. When the distance to a certain objective, such as a contact, is approximately known, the feet each size of bit must drill can be roughly estimated and the procedure of reaming as against continued drilling with dulling bits, etc., governed accordingly.

Permissible reduction in gage is less than in the ordinary drilling done for blasting purposes, since the hole must not only be large enough to pass the rod couplings but must in addition provide room for ejection of the cuttings. Clogging of sludge in holes of reduced diameter not only is liable to induce sticking of bits and breaking of rods but also results in a pronounced lag in the appearance of cuttings at the collar or sometimes in incomplete recovery, thus in part vitiating the results. The use of smaller-diameter steel in front of the standard size (1 inch ahead of 1¼ inch) at Chief Consolidated was not wholly satisfactory, since the lighter steel was subject to considerable vibration,[87] with resultant low effectiveness in transmitting blows to the face in long holes.

Broken or fissured ground presents obstacles, as in other methods of drilling; open fissures generally mean loss of the hole, since return of sludge is rendered impossible and mechanical difficulties of drilling are increased. Such openings can sometimes be bridged with a length of pipe by drilling a short distance into the far wall of the cavity, placing and wedging the casing, and continuing the hole with a smaller bit. Bains[88] has described the successful appli-

[85] Brown, R. K., Exploratory Deep-Hole Drilling: Comp. Air Mag., vol. 31, April, 1926, pp. 1593–1594.
[86] Bains, T. M., jr., The Gasoline Engine as a Mining Power Unit: Eng. and Min. Jour., vol. 125, 1928, pp. 1051–1052.
[87] Dobbel, Charles, work cited, p. 681.
[88] Bains, T. M., jr., work cited.

cation of this idea at the Memphis property in New Mexico. If the hole had not already been much reduced in gage when the water-course was struck, results were satisfactory.

Cementing or grouting is quite possible in this type of drilling, but generally it is more economical to abandon the hole and try again at a different location or direction than to undergo the expense of cementing, since the investment in a hole less than 150 feet deep is relatively not great, as compared to deeper and more costly bores where a considerable outlay of time and money would be justified for grouting a bad section in the hole. At the Tonopah-Belmont[89] a hole which had struck an open fissure at 103 feet was drilled a few feet farther in the hope that sludge would plug the crevice, but no water was returned. The hole was abandoned and a new one, started 5° to the left, was bottomed at 225 feet without loss of sludge.

Loss of time due to stuck bits or broken rods varies with the hardness of the ground, degree of fracturing, and other characteristics and is also in more or less direct proportion to the experience and degree of skill of the driller, as well as the quality of the equipment used. Satisfactory fishing tools have been developed and described in the technical press. No discussion of that phase of the subject will be given here.

Advance per machine shift ranges from 8 feet in excessively hard ground to 50 feet or more under the best conditions; the average advance is generally about 25 feet.

SAMPLING PRACTICE

Sampling the cuttings is of primary importance in any drilling program. It is a surprising fact that this feature of the work is often entrusted to the unsupervised drilling crew—men who are usually expert drill runners but often inexperienced in drill-hole sampling and ignorant or careless of its importance. Such men are out for footage and unless constantly watched are inclined to pay little heed to what is happening in the sludge box.

The most common method of sampling long holes consists simply in placing a powder box or carbide can below the collar of the hole where it will catch most of the sludge and replacing it with an empty box or can after the 3 feet or other distance chosen for the sample interval is drilled. Naturally a considerable loss of slimes is the corollary of such imperfect makeshifts and doubtless is often responsible for the "unreliable" assay returns reported by many operators for their long-hole drilling. The powder-box method has given accurate results in some instances,[90] but only because the fines carried about the same proportion of values as the coarse cuttings. When the ore is known to contain values in approximately uniform distribution throughout the various sizes from coarse chips to the finest slimes, a rough method which obtains enough of the material for assay may be sufficiently refined. On the other hand, in the more usual case of disproportionate values over the range of particle sizes that occur in drill sludge no sample can be accurate or reliable which

[89] Brown, R. K., Exploratory Deep-Hole Drilling: Comp. Air Mag., vol. 31, April, 1926, pp. 1593–1594.
[90] Dobbel, Charles, work cited, pp. 682–683.

is not truly representative of the entire volume of material broken by the bit. If it is worth while to undergo the expense of long-hole drilling at all it should certainly be worth while to go to the small additional trouble and expense of rendering the information gained from that drilling as complete and as accurate as possible. Some operators have found the long-hole drill extremely useful for proving or disproving the presence of ore but useless for providing any reliable information as to grade. Although in many instances the physical nature of the ground and the ore prevent accurate sampling by hammer-drill methods, in many others the faulty assay returns can be traced to faulty technique at the collar of the hole.

For accurate sampling of long holes, two requirements must be met. First, all the material cut during the sample interval must be driven from the hole; and second, all this material or a representative portion of it must be collected and included in the sample sent to the assay office.

The first requirement is the more easily satisfied. Most holes are drilled at a low angle above the horizontal—from 5° to 30°, according to local conditions—such that the sludge is readily washed out by the return water. In down holes air usually is required to aid the water in lifting out the cutting; the manner of introducing air has been already mentioned. In many instances it is impossible, in part because of the obstructions offered by the rod couplings, to clean out down holes completely after they have attained depth and suffered more or less reduction of gage, unless the rods are pulled and a blow-pipe is used. Holes inclined steeply upward present no difficulties in the matter of discharging sludge.

The second requirement—that of catching the sludge as it comes from the hole—is the weak link in the long-hole sampling chain. The common practice of placing a box or can beneath the collar has been discussed. A better scheme is to fix a piece of sheet metal, bent into the form of a shallow spout or lip, beneath the hole to prevent sludge from running down the wall behind the can or box. Probably the most effective method of catching sludge is that employed at Tonopah [91] and New Idria,[92] among other places.

A short piece of pipe (about 3 inches in diameter and 1 to 2 feet long) is split longitudinally for all but a few inches of its length, the split portion is spread open to form a launder, and the unsplit end is inserted in a hole drilled for the purpose a few inches below the long hole and connecting with it 6 to 12 inches from the collar. This launder or spout feeds the sludge into containers and is very effective in preventing loss by running down the walls.

With holes highly inclined above the horizontal it is difficult to effect a complete recovery of sludge on account of its tendency to run down the rods. So far as we are aware no entirely satisfactory means to combat this difficulty has been devised. Pans, gaskets, and sacks have been employed with indifferent or only partial success. A short piece of casing in the collar of the hole, fitted with a stuffing box of some form, might be applicable, provided the difficulties of vibration and possible impaired drilling efficiency could be overcome.

[91] Brown, R. K., work cited.
[92] Moorehead, W. R., Methods and Costs of Mining Quicksilver Ore at the New Idria Mine, San Benito County, Calif.: Inf. Circ. 6462, Bureau of Mines, 1931, pp. 3–4.

Containers for catching sludge may consist simply of a powder box or single carbide can as previously mentioned, or of settling tubs, sludge boxes, or other arrangements. Many mines reduce the volume of material handled by cutting out part of the sludge in a riffle-sample splitter; if carefully done this does not seem to vitiate the results.

When one small container is used slimes are inevitably lost. To prevent such loss, sludge receptacles should provide ample opportunity for settlement of fine material. A large tub will often accomplish this purpose when a sample splitter is used to reduce the volume retained. In this case the water is decanted when clear, and the solids are cleaned out from the tub and filtered or dried over a fire.

A satisfactory method of recovering sludge—one that has proved itself at several mines—has been described as used at Tonopah.[93] With this set-up the sludge flows from a launder into a carbide can, overflowing thence through two successively shorter cans at lower elevations. Virtually all the cuttings settle out before the final overflow leaves the system as clear water comparatively free of solids. At the end of each sample interval the clear water in the cans is decanted; the contents of the two smaller cans are dumped into the first can and allowed to settle, when the remaining water is decanted and the sample is collected for drying and assay.

Cuttings should always receive regular attention by a geologist or other experienced man familiar with the ore and country rock. At many mines a regular file of cuttings is maintained, the material being kept in small jars or bottles or mounted on cards on which has been noted all pertinent information, such as location, direction and depth of hole, dates of drilling, position of the sample in the hole, assay (if ore), petrographic notes, and the like.

RECORDING DATA

Long holes should be logged in accurate detail in the same general way as diamond or churn drill holes. Generally a driller's log and a geologist's log are kept, the former giving such information as location, course and inclination of hole, dates started and stopped, depths drilled each shift, bits used, samples taken (if taken by operator), time lost in delays, and general remarks, such as changes in formation, color of sludge, or hardness, fractured or broken ground noted by behavior of drill, loss of return water, and so on.

The geologist's log should record the location, direction, depth of hole, and dates; feet of various formations penetrated, presence of gouge, broken ground, dikes, veins, contacts, and the like; description of rocks cut; assays where made; and similar data. It has been found possible in many instances to obtain a surprising amount of geological information from careful study of drill cuttings; by making detailed records of such information at the time the study is made the results are preserved as a source of reliable information for the future.

[93] Brown, R. K., work cited.

TABLE 6.—*Typical test-hole drilling data*

Mine or district and State	Kind of rock	Type of drill [1]	Depth of holes, feet	Feet per drill-shift	Purpose of drilling	Results reported	Cost per foot	
							Labor	Total
Burra-Burra, Tennessee	Schists, graywacke, massive sulphide.	A	Up to 150	25	Outlining ore body	Satisfactory; best on inclination+15° or over.		$0.80
Acme, Tri-State	Cherty limestone	A			Prospecting walls	Cuttings useful indicator, assays unreliable.		.64
Do	do	B	17		Testing bottoms	Reliable samples		.57
Ray, Ariz	Schist	A	Max. 90	23	Prospecting instead of raising +45°.	Satisfactory		
No. 1, Menominee range, Michigan.	Hematite and iron formation.	A			Testing walls	Good in soft ore; poor in hard chert.		
Morning, Idaho	Quartzite	A	{Ave. 46 / Max. 129}	[2] 12	Testing vein walls	Satisfactory	$0.92	1.10
Mascot, Tenn	Dolomitic limestone	D			Sampling stope backs	do		
Cananea, Mexico	{Porphyry and hard limestone.}	A	{35 to 125 / Ave. 85}	18½	Flat holes to delimit ore bodies.	do		
Engels, California	Diorite	D	7.7		Cuttings from 2 or 3 stope holes daily for samples.	do		
Park-Utah, Utah	Quartzite	A	Max. 88		Prospecting 2 holes only	Unsatisfactory; steel failed		
Pilares, Mexico	Brecciated volcanics	E		5	Sampling	Satisfactory		
Teck-Hughes, Ontario	Silicified syenite and porphyry, hard.	D	5		Testing vein walls every 10 feet.	Satisfactory; assays not used in reserve estimates.		
Fierro, N. Mex	Hard magnetite and limestone.	F	20		Prospecting ahead. Assays used in grade estimates.	Very satisfactory		
Do	do	A		8.84	Prospecting	More costly, less accurate than diamond drilling.	1.217	2.821
Pecos, N. Mex	Schist and diorite	A	50 to 100		Prospecting for parallel ore bodies.	Satisfactory	1.26	1.98
Black Rock, Butte, Mont	Granite	A			Prospecting. Not now used	Holes salted by soft-ore streaks. Not reliable for grade of ore.		
Page, Idaho	Quartzite	A			Prospecting walls. Not now used.	Limited range. Slow and costly in hard rock.		
Spring Hill, Mont	Hard contact met. ore and rocks.	A	Max. 35		Exploring to contact	Unsatisfactory in hard rock		
Eagle-Picher lead, Oklahoma.[3]	Chert and limestone	A	Max. 148		Exploration	Good ore found. Valuable for negative information.		1.69
Evans-Wallower lead, Oklahoma.[3]	do	A			do	Eliminated much ground thought ore bearing.		1.00
Federal M. & S. Co., Kansas[3]	do	A	Max. 147		do	Located many new ore bodies		1.90
Canam Metals, Oklahoma[3]	do	A			do	Several ore bodies found. Cheaper than other methods.		1.70
Missouri-Kansas Zinc Corporation.	Chert and limestone	A	Max. 152		Exploration often at steep plus angles.	Very satisfactory		60-.70
New Idria, California	Shale, sandstone, serpentine	A	{Ave. 99 / Max. 228}	30	Exploration	do		
Chief Consolidated, Utah[4]	Limestone and ore	A	Max. 272	23	do	do		.75
Southeast Missouri[6]	Limestone	A	35 to 78	35	do	75 holes drilled; satisfactory	[5] .44	.97
Do	do	C	Max. 22		Testing backs, floors, and walls.	Satisfactory	[7] .16	
Tonopah Belmont, Nevada.[8]		A	Max. 256	34	Exploration, sampling walls	Good	(9)	
Jarbidge, Nevada[10]	Volcanics		50 to 60		Exploration	As good as diamond drills and cheaper.		
Edwards, N. Y	Zinc ore in dolomite	A	Ave. 43		Testing walls	25 per cent deducted from assays.		.99

[1] A, Heavy drifter with special independent rotation; B, piston machine on tripod; C, jack hammer with pneumatic feed; D, standard medium weight drifter; E, stopers; F, jack hammer.

[2] For holes up to 100 feet deep.

[3] Netzeband, W. F., Prospecting, with the Long-Hole Drill in the Tri-State Zinc-Lead District: Min. and Met., June, 1930, pp. 295–296.

[4] Dobbel, Chas. A., Deep-Hole Prospecting at the Chief Consolidated Mines: Trans. Am. Inst. Min. and Met. Eng., vol. 72, 1925, pp. 677–689.

[5] Year 1924.

[6] Poston, Roy H., Leyner Drill in Underground Prospecting: Eng. and Min. Jour., vol. 118, Nov. 29, 1924, pp. 856–857.

[7] Approximate.

[8] Brown, R. K., Exploratory Deep-Hole Drilling: Comp. Air Mag., April, 1926, pp. 1593–1594.

[9] Time studies made. See footnote 8.

[10] Park, John Furness, Mining Methods in Jarbidge District: Trans. Am. Inst. Min. and Met. Eng., vol. 72, 1925, pp. 518–528.

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