R. 1 E.

EXPLANATION

Maquoketa shale

ncludes Dubuque shaly member of possible upper Ordovician age.

Decorah formation

Lead pits of irregular arrangement

Zinc sulfide mine working

Vertical shear zone

Shear zone, showing dip

Dashed where inferred.

Strike and dip of beds

Strike and dip of joints

Strike of vertical joints

Strike and dip of multiple joint system

Structure contours

Lead mine or prospect shaft

Lead adit, open

Lead adit, closed

Drill hole

Drill hole intersecting zinc of ore grade

Drill hole intersecting lead

of ore grade

Zinc sulfide present on mine dump

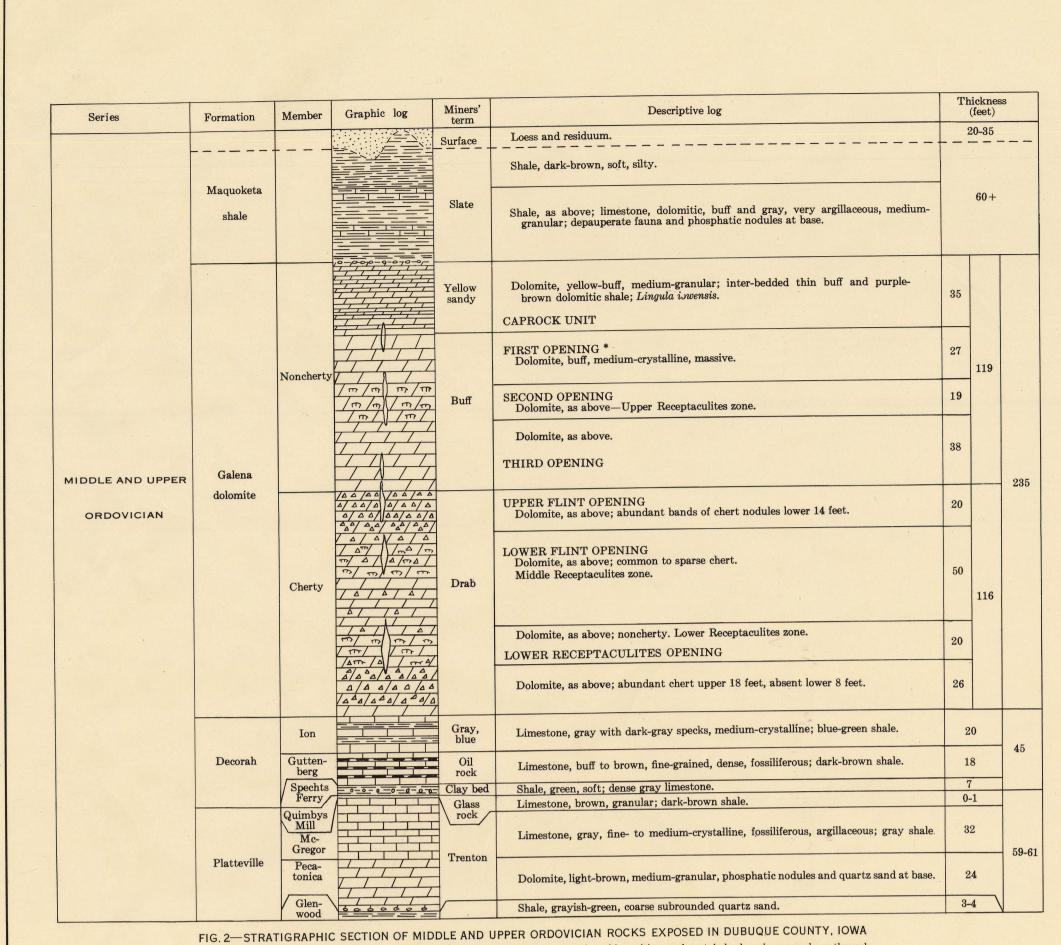
Zinc carbonate present on mine dump

Point used for structural control based or

outcrop or auger-hole data

Spot elevation

A 36+5



*Openings are joints enlarged by solution. They commonly occupy the same stratigraphic positions and contain lead ore in many places throughout the zinc-lead district of Wisconsin, Illinois, and Iowa.

GEOLOGY AND ZINC-LEAD DEPOSITS IN THE DURANGO AREA DUBUQUE COUNTY, IOWA

Arthur E. Flint and C. Ervin Brown

INTRODUCTION

Geologic investigations were begun in Iowa to appraise: (1) the possible occurrence of zinc ore in strata that elsewhere in the Upper Mississippi Valley zinc-lead district have been the principal sites of zinc concentration; and (2) lead ore of the type known as "crevice deposits," which were mined so extensively during the 19th century in Dubuque County, Iowa, but have been mined very little since 1910. The area chosen for initial study is northwest of Dubuque, Iowa, and comprises 11 square miles in the vicinity of Durango (fig. 1). The geologic report

and map of the Durango area is the first of a series of such reports and maps

resulting from investigations by the U. S. Geological Survey in cooperation with the Iowa Geological Survey. Horizontal control for the base map was adapted from aerial photographs made in 1940 by the U. S. Department of Agriculture. As far as possible, distortion in the photos was adjusted to an unpublished section grid survey by the Works Progress Administration made prior to 1939. The only available vertical control

was obtained from spot altitudes along U. S. Highway 52. Vertical control was extended from these points to all parts of the area by plane-table and telescopic alidade surveys. Field work included the examination of all bedrock exposures, mine drifts, shafts, and dumps for data pertaining to key horizons; to the orientation of fractures; to the nature of mined ore, gangue minerals, and host rocks; and to the stratigraphic position of the beds in which the ore was deposited. These data were augmented by descriptions of cuttings from wells and exploratory

drill holes. Altitudes of key horizons and well collars were determined by

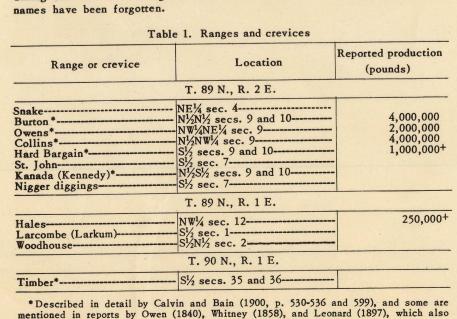
plane-table and alidade surveys. This report is based on field work begun in October 1951 and completed in November 1952. The authors acknowledge the assistance of members of the Dubuque County Engineer's office for supplying the locations of U. S. Highway 52 benchmarks, and the assistance of J. E. Miller for supplying exploratory drilling data for use in preparing the map.

HISTORY AND PRODUCTION

The earliest geologic reports that deal with mineral deposits in the vicinity of Dubuque, Iowa, indicate that mining of lead ore (galena) in the Durango area was probably begun by Julien Dubuque between 1788 and 1810. After Dubuque's death in 1810 work in the Iowa mines was continued by Indians until 1833, when the land west of the Mississippi River was opened by the Government to settlers and lead mining was vigorously undertaken. Despite a few minor reversals the production of lead increased steadily, reaching a maximum in 1846-47. From that date production was uniform until about 1857, when it began to decrease. Except for brief increases in 1887-88 and in 1905-7, production continued to drop, and in 1910 the last of the large mines in Iowa shut down. Since that date lead mining has been sporadic and the operations have been small.

Zinc ore, principally zinc carbonate but including also zinc sulfide, never has been as economically important in Iowa as lead ore. Zinc was first mined about 1860; before that time the ore had been considered waste rock. Accurate production figures for lead and zinc are not available either for the Durango area or for the general Dubuque subdistrict.

Names and locations of lead crevices and ranges in the Durango area that are mentioned in earlier reports are listed in table 1. The Timber range also contained important zinc carbonate deposits, and the Larcombe range was mined primarily for limonite, which was used as iron ore. Most of the ranges mapped during the current investigation are either unnamed or, more probably, their



contain additional historical data pertinent to the Durango area.

ROCK STRATA

The geologic map shows the areal distribution of bedrock strata, and figure 2 gives the names, thicknesses, and gross lithology of the potential ore-bearing Galena dolomite, Decorah formation, and Platteville formation and of the lower part of the Maquoketa shale, which probably is not ore-bearing. Beds of the Platteville formation, the lowest stratigraphic unit pertinent to this investigation, do not crop out in the area mapped but are exposed within half a mile of the east boundary of that area along the Little Maquoketa River in the SW1/4 sec. 34, T. 90 N., R. 2 E. Data from drilling indicate that the formation is about 60 feet thick in the Durango area. The basal Glenwood shale member and the overlying Pecatonica dolomite member, both of the Platteville formation, contain only a few disseminated sphalerite or galena crystals in other parts of the zinc-lead district. The overlying McGregor limestone member (part of the "Trenton" of local usage) of the Platteville formation, contains zinc ore in some of the mines in Wisconsin, and until proved otherwise it should be considered a potential host rock for ore in the Durango area. The Quimbys Mill limestone member of the Platteville, which is locally known

as "glass rock," overlies the McGregor limestone member and is very similar in its dense sublithographic nature to the upper part of the McGregor. Although the Quimbys Mill is darker brown than the McGregor, it is so thin that the two units are difficult to differentiate in cuttings from churn-drill holes. Therefore it is not known if the Quimbys Mill member is present in all of the Durango area. Overlying the Quimbys Mill member is the Spechts Ferry shale member ("clay bed" of local usage), the basal unit of the Decorah formation. Because this unit is mainly shale, it is considered a poor host rock for ore, although locally it does contain traces of lead and zinc. The Spechts Ferry shale member crops out along the west side of U. S. Highway 52 in the NW1/4NW1/4 sec. 34, T. 90 N., R. 2 E., about an eighth of a mile east of the mapped area. Overlying the Spechts Ferry is the Guttenberg limestone member ("oil rock"

of local usage) of the Decorah formation, a potentially good host rock for zinc ore. This unit contains zinc and lead deposits elsewhere in the district, but in Iowa it has been very little explored. No outcrop of Guttenberg occurs in the Durango area, but it crops out in the same exposure as the Spechts Ferry member west of U. S. Highway 52. It also appears as the lowest exposed beds in a large quarry west of Highway 52 in the SE1/4 sec. 3, T. 89 N., R. 2 E., and in a gully south of the Chicago & Great Western Railroad in the SE1/4 sec. 3, T. 89 N., R. 2 E. These exposures are east of the mapped area, and in none of them is the full thickness of the Guttenberg exposed. The Guttenberg limestone member is normally 17 to 18 feet thick, but leaching and compaction locally may reduce its thickness. The Ion dolomite member of the Decorah formation, which overlies the Gut-

tenberg, is probably the most important host rock for zinc ore throughout the mining district. Local miners recognize two subordinate units in the Ion-the "gray beds" above and the "blue beds" below. Where the member, which is limestone in most of the Durango area, is altered to dolomite, green shale partings serve to distinguish it from overlying nonshaly dolomite beds. The Ion crops out in a southward-extending ravine north of U. S. Highway 52 in the NE¼SE¼ sec. 33, T. 90 N., R. 2 E. Where unaltered, it is consistently 20 feet thick, but leaching and compaction may thin the unit. The Galena dolomite, which overlies the Decorah formation and forms bluffs in the Durango area, is an important host rock for both zinc and lead. Chert (flint) is common in the lower half of the formation but is absent in the upper

half, thus providing a natural division of the formation into two easily recogniz-From the lower, cherty unit of the Galena dolomite, normally about 112 feet thick, have been mined the important zinc and lead deposits throughout the mineralized district. The upper, noncherty unit, normally about 117 feet thick, however, has included most of the mined lead deposits and one important zinc deposit

The important zones of lead and zinc concentration, and the recognizable stratigraphic zones and key horizons used for structural datum points throughout he cherty and noncherty units, are indicated in figure 2. Except for one outcrop of the upper strata of the Decorah formation and a few poor exposures of Maquoketa shale, all the field data are from the abundant outcrops of the Galena dolomite in the Durango area.

The Magnoketa shale, where present in the mapped area, is very soft and easily eroded. Consequently, it commonly is covered with surficial material and outcrops are sparse. Field data concerning this information were obtained principally by use of the hand auger. No evidence suggesting commercial deposits of either lead or zinc was observed in this formation, but the basal 2 to 3 feet of Maquoketa shale in most places contain small amounts of zinc and iron sulfide. ROCK ALTERATION

Common alterations of the host rock adjacent to zinc and lead deposits in the Durango area are leaching, dolomitization, and less commonly silicification. Evidence of only leaching is conspicuous in and around the lead and zinc crevice deposits of the Galena dolomite, but evidences of all three processes are known in the zinc deposits of the Decorah formation.

Leaching of the Galena dolomite, principally below the water table, has reduced much of the hard crystalline carbonate rock to an incoherent sand of individual dolomite crystals and has left the walls of the dissolved areas with a honeycomb texture. Leaching of the dolomite has been an important factor in the localization of lead ore. Leaching and compaction of strata of the Decorah, particularly in the lower part of the Ion member ("blue" beds) and in the Guttenberg member ("oil rock"), has left residues of green and chocolate-brown shale and has thinned the units locally to as little as 30 percent of their normal thicknesses. Unlike the leaching in the higher beds of the Galena dolomite, where the alteration is confined mainly to the immediate vicinity of fractures in the rock, the thinning, particularly in the Guttenberg member, is known to extend over an area several hundred feet wide and at least 2,000 feet long. An example of such an area is centered in

Almost everywhere that significant leaching and compaction occurred in the

RICHLAND

EXPLANATION

2. Hazel Green—Shullsburg area 3-216

Mineral Investigations Field Studies maps

4. Mifflin—Cokerville area

MF 3—Beetown area MF 15-Area east of Cuba City

5. Potosi area

FIGURE 1. INDEX MAPS OF WISCONSIN-ILLINOIS-IOWA ZINC-

LEAD DISTRICT

Ion and Guttenberg members, the limestone strata have been dolomitized, and have a sugary appearance instead of the finely granular to sublithographic texture of the unaltered limestone. Silicification of the limestone or dolomite has been noted in subsurface samples taken from bore holes in the Durango area. Evidence of silicification is more common, however, in other parts of the zinc-lead district. Where observed in the Durango area the silica has preserved minute structures present in the replaced limestone, and the megascopic appearance of the rock has not changed.

the NW\4SE\4 sec. 5.

joints are present but not common.

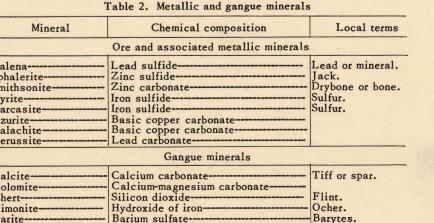
STRUCTURE

The presence of silica may be easily detected only by the increased hardness

The regional dip of the rock strata in the general vicinity of Dubuque, Iowa, is southwestward 15 to 20 feet per mile. The Durango area lies on the south limb of an anticline that plunges gently westward, and the average dip in the mapped area is between 30 and 40 feet per mile. Superimposed on the major anticlinal structure are several minor anticlines (upwarped areas) and synclines (downwarped areas). For the most part these folds probably originated as a response to lateral compressive forces that have been applied to the rock strata. In a few places, however, notably in the SE1/4SW1/4

sec. 6 and across the southern part of sec. 35, the narrow elongate depressions are believed to be due entirely to solutional removal and compaction of underlying rock along fractures in the bedrock. Beds of the Galena dolomite and Decorah formation exposed in and near the Durango area are characterized by well-developed, vertical joints. The most distinctive and most continuous joints trend westward. Locally, however, joints of northeasterly or northwesterly trend may be more prominent. Northward-trending

Composition of the ores. - Ore deposits in the Durango area have simple mineral associations. Nothing in the drill samples or mine dumps indicates that the deposits differ essentially in mineral suite from those that have been investigated in mines elsewhere in the mining district. Table 2 shows the metallic and gangue minerals observed in the area mapped.



At present (1953) only galena and sphalerite have commercial importance. Until about 1910, however, smithsonite or "drybone" was an important commercial mineral in the Durango area and may assume economic importance again. Also, in 1896-97, limonite was mined as an iron ore from the Larcombe (Larkum) range in the S½ sec. 1 and the SW¼SW¼ sec. 6. Moderately abundant pyrite and marcasite accompany the zinc deposits in the Decorah formation, and the limonite of the Larcombe range in the middle of the Galena dolomite is an undoubted oxidized body of those minerals. Copper and barium minerals are sparse. A mine dump in the NE¼SE¼ sec. 4 contains a moderate amount of copper carbonate, and the adjacent shaft is believed to be the one excavated by Charles Singer. who in 1945 reported penetrating, at a depth of about 100 feet, a 3-inch sheet of green talclike clay that assayed 42 percent metallic copper. None of the other dumps examined, however, contain more than traces of copper minerals, and commercial copper deposits in the Durango area are considered unlikely. Occurrence of ore minerals. - The lead-ore mineral galena commonly occurs as masses of large crystals called "cog lead," less commonly as small individual fillings. The galena where observed above water table was commonly associated Timber range, galena may be associated with smith sonite. On dumps along the

crystals called "dice mineral," as veins called "sheets," and as irregular vug with significant amounts of limonite (ocher). Locally, as at the Ewing diggings half a mile west-southwest of the village of Durango (S½SE¼ sec. 36) on the Timber range in the SW1/4 sec. 35 coarsely crystalline barite was observed. Calcite is sparse to absent both on the lead mine dumps and in the accessible mines. However, large blocks of concentrically banded aragonite ("onyx") are present on a few mine dumps, notably on those in the SW1/4SE1/4 sec. 4. The blocks appear to be from a typical cave deposit, and probably the mineral has no genetic relationship to the galena but was introduced much later. The zinc-ore mineral sphalerite occurs as disseminated crystals and as veins. On the mine dump at the Bonson shaft, SE\(^4\SW\)\(^4\) sec. 6, abundant sphalerite as fracture filling and breccia filling in the host rock was observed. On dumps about 1,000 feet east of the Bonson shaft, sphalerite occurs as disseminated

with the sphalerite are pyrite and marcasite. Locally, particularly in deposits in the middle part of the Galena dolomite, galena also occurs with sphalerite, and small amounts of galena were observed in zinc-mineralized strata of the Guttenberg member. Uncommonly, many of the ore and associated minerals may be observed in one waste rock pile. For example, at the mine dump on the St. John crevice in the NE¼SW¼ sec. 7, sphalerite, galena, pyrite, marcasite, calcite, and gypsum (sel-

crystals and as clusters of crystals. The most abundant minerals associated

Lead deposits.-Localization of lead deposits in the Durango area appears to have been controlled by the limited stratigraphic zones of more soluble dolomite beds, and the vertical or nearly vertical joints intersecting those beds. Waters percolating along very slightly opened joints in the rock removed by solution a part of the dolomite in the more soluble zones and created voids into which the lead sulfide was deposited. To such joints widened by solution the early miners gave the name "crevice," and Whitney (1858) introduced the term "gash vein" for them. The term "range" may be used to describe several closely spaced parallel mineralized crevices. The principal crevices in the Durango area trend nearly east. The Timber range, the Burton and Owens ranges, the St. John crevice, and the Hard Bargain range are all so oriented. A few crevices, one of which is indicated by the irregular alinement of shafts in the SW1/4SE1/4 sec. 4, trend northwestward. A group of crevices trend N. 30° E. in the central part of the \mathbb{W}_{2}^{1} sec. 6. Also, several

crevices that trend N. 150 E. were mined in the south bluff of the Little Maguo-

keta River in the SW1/NE1/4 sec. 5, and one important unnamed range in the S1/2

The main ore bodies in the numerous crevices and ranges indicated on the map

occurred in one or more of several stratigraphic zones. The void or opening into

which the ore was deposited in each zone has been named, and these are listed

sec. 6 strikes N. /30 E.

Table 3. Mineralized openings Average depth in feet below the top of the Galena dolomite

Top of opening Floor of opening

The first opening has been extensively mined in the Durango area. It occurs in a zone of lithologic change from even-bedded finely granular shaly dolomite, downward to massive or thick-bedded fine- to medium-crystalline dolomite. Its caprock, which is the name given to the first indurated relatively unleached hard bed or group of beds above any given opening, is readily recognizable whether or not the beds below have been leached. This caprock unit consists of beds whose unique sequence of thicknesses in ascending order is 1.7 feet, 0.5 foot, and 3.2 feet. The last is a massive bed in which subordinate stratification may appear on weathered surfaces. The 0.5-foot bed weathers rapidly, forming a deep horizontal reentrant. The caprock of the first opening is the one commonly cited in the references, because caprocks of other openings are not so easily

the zone; this opening begins at 24 feet and continues to 46 feet below the base of the caprock of the first opening. The relationship of the second opening to this zone is used in locating the normal stratigraphic position of the opening, where other evidence of it is lacking. The third opening, from which was mined much of the ore in the Burton and Owens ranges, the Timber range, and other ranges in the Durango area, begins at 7 feet and continues to 14 feet above the easily recognized top of the cherty member (fig. 2). The uppermost chert bed of the cherty member consists of platy nodules that on a weathered surface lie in a bedding-plane reentrant in massive to thick-bedded dolomite. This isolated chert band lies 5 to 6 feet above a zone

The second opening commonly is in the upper Receptaculites zone, which is

named for the fossil Receptaculites (sunflower coral) that is present throughout

of very cherty dolomite that is 18 to 20 feet thick. The upper flint opening is in the upper 10 feet of this very cherty dolomite. The beds in this interval virtually everywhere show the effects of solution, whether cut by open joints or not. Some of the larger openings in the Durango area are in this zone, but in much of the mapped area it has not been explored because of its depth below the surface. The lower flint opening is normally 20 to 28 feet below the base of the upper flint opening, but locally the two openings have joined and make one continuous

vertical opening. Little is known in the Durango area about this opening, for none of the few mines in which it is exposed are accessible for examination. The lowest stratigraphic zone that contains lead deposits in crevices is the lower Receptaculites opening. This opening is 20 to 30 feet above the base of the Galena dolomite. The largest continuous lead mine in the zinc-lead district is in this opening near Beetown, Wis., but because of its excessive depth in most of the Durango area, this opening has not been investigated for lead ore deposits. An opening in the lower Receptaculites zone is exposed in a road cut about 1,300 feet north of the northeast corner of the mapped area (NE1/4NE1/4 sec. 33, T. 90 N., R. 2 E.). The openings proper may be voids in the rock, but commonly they are filled with punky dolomite boulders, dolomite, sand, and clay, which are residual remains of the leached rock. Some of the clay filling, however, has been carried in by downward and laterally moving waters as indicated by recognizable Maquo-

forming "chimneys," which may extend to a considerable depth. Such vertical

joining of openings is not continuous along the crevice but in most places occurs only for distances of 20 to 30 feet. A drill hole in the SE1/SW1/4 sec. 6 penetrated more than 100 feet of unconsolidated dolomite sand and residual clay in one of these solution openings.

Scale 1:12000

R. 2 E.

With very few exceptions, the larger openings and the major lead deposits occur where the main crevice or range is intersected by less prominent joints. These intersections are called "crossings," and because they in part control the location of openings along crevices, the openings, and consequently the lead deposits, commonly are continuous for only short distances. Deposits are concentrated, however, at a great many places along one range or crevice and consequently some of these gash veins have been mined at close-spaced intervals for several miles, as those in the Timber range and the St. John crevice. The lack of continuity of the ore partly accounts for the unusual number of shafts that have been dug along many of the crevices. In several places erosion on gentle slopes has exposed an opening, and lead

ore has been concentrated in the unconsolidated surficial material. This type

of occurrence is called "surface mineral," and such areas have been mined by a series of closely spaced pits, as near the center of the W\(\frac{1}{2}\)W\(\frac{1}{2}\) sec. 4. Zinc deposits. - Details concerning zinc deposits in the Durango area are not known. Except for the zinc sulfide mined from the Bonson shaft (SE¼SW¼ sec. 6), all the zinc mines in the Durango area have produced zinc carbonate (drybone), which generally occurs in the same manner as crevice lead deposits. Concentrations of zinc carbonate and lead sulfide may occur together, or one may grade into the other horizontally or vertically. In the opencut at the Ewing diggings (near the center of the S½S½SE¼ sec. 36) on the Timber range, some mineralized fractures are vertical; others are inclined and are similar in some respects to the type of fractures that control stratigraphically lower zinc deposits described later. The zinc carbonate observed in the old mines and on mine dumps is a porous, cellular mass that looks like the porous interior of dried bones. Less commonly it forms a botryoidal coating on the crevice walls and in some places appears as thin veinlets in the host rock. Because it characteristically occurs with limonite (ocher), it commonly has a rusty color, but a freshly broken sur-

face is light gray to white. The largest tonnage of zinc carbonate was produced at the Ewing diggings. The mine was originally worked for lead, before the time that zinc had commercial value. Whitney (1858, p. 470) as early as 1857 observed zinc carbonate at the Ewing diggings, and Leonard (1897, p. 47) reported that these mines were worked extensively for zinc about 1894-96. Zinc carbonate was observed on dumps elsewhere along the Timber range, and small amounts were present on dumps along the prominent crevice in the SE¼ sec. 6. Only one shaft in the Durango area penetrated beds below the lower Recen-

taculites zone. This shaft, the Bonson (sec. 6), was dug originally to a depth of 90 feet to mine lead from the lower flint opening. It was deepened about 1910 to a reported depth of 165 feet to mine a zinc sulfide deposit, which presumably had been found by drilling. Drifts were driven both east and west from the shaft. Although the zinc on the dumps appears to be of ore grade, the price of zinc at the time of operation apparently was not sufficient to make mining profitable. The zinc sulfide at this shaft occurs as a fracture filling in broken rock, similar to the occurrence in some of the large zinc mines elsewhere in the zinc-lead district. In this respect it differs from other zinc sulfide occurrences noted in the Durango area, which have individual crystals or clusters disseminated through In the Wisconsin and Illinois parts of the zinc-lead district zinc ore has been

concentrated along features in the rock described as "pitches" and "flats." Pitches are mineralized inclined fractures along which differential movement has offset the beds (reverse faults). The pitches appear to be related to folding of the strata and probably result from lateral compression that initiated the fracketa shale and minute Maquoketa fossils that have been found in crevices as tures in the rock. Solution and compaction of the beds opened these fractures, much as 100 feet below the top of the Galena dolomite. Caves more than 30 feet and the sphalerite and associated minerals were deposited in the open areas. wide and more than 15 feet high have formed where several small openings along Flats are deposits along bedding planes separated by solution or by flexing of closely spaced joints have coalesced. Openings in a crevice may join vertically, the beds. Commonly the two features are associated in ore deposits. Very few exploratory holes in the vicinity of Dubuque, Iowa, have been drilled area in the E1/2 sec. 5 is one example of such a structure; another is in the SW1/4

deeply enough to intersect the Decorah and lower Galena strata, in which zinc deposits are found elsewhere in the zinc-lead district; for this reason the presence of zinc ore in those strata in the Durango area is problematical.

Collins crevice

CONCLUSIONS AND RECOMMENDATIONS Lead sulfide deposits. - Several observed facts resulting from this investigation indicate that many commercial lead deposits remain in the Durango area. First, most of the lead mining to date has been concentrated where stream dissection has encountered crevice systems and has given surface indications of lead deposits. From these discovery areas mines have been extended back under uplands and drainage divides, but in many places the crevices or ranges have been followed for distances of only a few hundred feet. Those that have been prospected adequately have consistently produced lead ore at crossings for distances of more than a mile. The Timber range, owing primarily to its location along the south bluff of the Little Maquoketa River Valley, has been

mined for more than 2 miles. Second, in many places not all of the lower openings that may occur in a fracture have been explored or mined. For example, the mine dumps at the eastern end of the Burton range contain ocherous chert. Farther west, however, along the Burton range and along the Owens range as well, no chert appears on the dumps. Thus the upper flint opening appears to have been mined only in the eastern part of the Burton range.

In the Timber range, the upper flint opening produced much ore for most of its length; but for the western half mile of the range the lack of chert in the waste rock indicates that the upper flint opening was not mined because at that time it was probably below the water table. At the time most of the mining was done in this area, pumps were inadequate

to permit mining to proceed below the water table, and in only a few places were pumps installed. Thus, virtually all of the lead deposits that were mined were above the water table, and those below it at that time presumably remain. At least some of these deposits undoubtedly have been drained by the progressive lowering of the water table in this area during the past 50 years. Mining of crevice lead deposits is relatively simple. Much of the lead ore lies in unconsolidated or poorly consolidated rock, which permits the separation of the ore from the gangue without milling. Little blasting is required, and the

ore consequently is not fragmented. The less important fine galena fragments are sometimes recovered by a simple iig. Crevice lead deposits present a difficult, twofold prospecting problem. They are hard to locate by vertical drill holes because of their narrow width; and where found by drilling, no accurate estimate of the size of the ore body or its exact stratigraphic occurrence can be made from the drilling samples, because the galena is fragmented and falls down the hole. Where exploratory drilling has been employed to find lead deposits, the location of holes no more than 15 to 20 feet apart in a line across the crevice and drilling successive lines of holes at 100- to 150-foot intervals along the crevice have proved practical. Shaft sinking as an alternate prospecting method is expensive but has been very profitable in some places. Sites for such an operation should be selected carefully. Shafts on the extension of mined linear bodies or in unmined areas between mines offer good possibility of success. Because of the constant or nearly constant direction of crevices, likely localities are relatively easy to find in the Durango area.

An elementary knowledge of the relative vertical positions of openings and

key horizons in the Galena dolomite will save much unprofitable labor in prospecting for or mining crevice lead deposits. Dubuque subdistrict, it will probably be in the exploitation of pitch-and-flat zinc Geol. Survey Ann. Rept. (1899), v. 10, p. 379-622, 8 pls. synclinal and basinal structures throughout the zinc-lead district, and the most significant result of this investigation is the finding and mapping of stratigraphic downwarps in the Durango area, similar to those that elsewhere in the mining district contain pitch-and-flat zinc deposits. The slightly arcuate downwarped

sec. 8. The presence of these folds is no guarantee of associated zinc ore deposits, but the absence of such structures suggests that zinc mineralized areas are probably insignificant or lacking. The locations and trends of downwarped

Hard Bargain range

Geology by A. E. Flint and C. E. Brown, 1951-52.

areas also are an important aid in selecting areas to prospect. Exploration initiated along known synclines and basins has a greater possibility of penetrating ore than exploration started in areas of unmapped bedrock structures. Exploration by cable-tool drilling is the standard prospecting method for pitchand-flat deposits; but diamond drilling, which produces a relatively solid column of rock, called core, also has been used. Of the two types, churn or cabletool drilling is less expensive. Diamond drilling provides information of mineral associations and type of deposits that cannot be obtained from fragmented churndrill samples; sample recovery, however, in soft or broken rock as a rule is poor-a marked disadvantage.

Standard drilling procedures derived from experience throughout the zinc-lead district are outlined below: Lines of drill holes are located across the axes of synclines; the holes are spaced 50 to 100 feet apart. These lines of drill holes are repeated at intervals of several hundred feet along the axial trend of the downwarped structures. Areas surrounding holes that penetrate zinc-mineralized strata are further explored by additional, more closely spaced holes. In areas where bedrock outcrops are sparse to absent, grid drilling has been employed to find the downwarped bedrock areas and, in turn, ore concentrations. In this system of prospecting, holes are spaced 500 to 1,000 feet apart to form a grid. Additional holes are drilled in the gridded area for data to clarify the interpretation of geologic structure and to get additional information near holes that penetrate zinc-mineralized zones in the primary grid. A reasonably accurate estimate of the amount of minable ore in a deposit can be made from drilling data. Rock alteration associated with zinc deposits is a great aid to finding ore. The most readily observed change in the ore host rock is caused by leaching and compaction-thinning of strata of the Decorah formation, particularly of the Guttenberg limestone member. Leaching and removal of the carbonate constituents of this member produces a dark-brown calcareous shale. A place where a drill hole has penetrated thin brown shaly Guttenberg strata deserves further exploration. The thinning of the strata by solution and compaction is not limited to the Decorah formation but occurs less significantly in the Galena dolomite. Alteration of limestone to dolomite commonly accompanied zinc mineralization in the district, and this change in the rock may indicate adjacent zinc-mineralized areas. Moreover, both dolomitization and iron sulfide mineralization commonly ex-

tend peripherally beyond zinc concentrations. Penetration of either dolomite or iron sulfide by exploratory holes suggests the possibility of zinc-mineralized Zinc carbonate deposits. - Zinc carbonate deposits may occur in either crevice or pitch-and-flat concentrations, but because zinc carbonate has little value in the present market, deposits can be considered only as a reserve of zinc for possible

future exploitation. Iron sulfide deposits.-Iron sulfide that is associated with zinc ore has been, but is not now, recovered as a byproduct of zinc mining. This mineral has been used as a source of sulfur dioxide for the manufacture of sulfuric acid, and in the future it may have economic value for the same purpose. No large deposits of iron sulfide are known in the Durango area, but the abundance of iron oxide associated with the lead deposits above the water table suggests that the unoxidized sulfide form is equally abundant below the water table.

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