Welfare, National Inst. of Health, Project EF-00160-05, University of Southern California, Los Angeles, 1965, 77 pp.
[17] Merz, R. C., and Stone, R., "Special Studies of a Sanitary Landfill: First Progress Report," Dept. of Health, Education, and Welfare, U.S. Public Health Service Grant R01 SW 00028-06, University of Southern California, Los Angeles, 1966, 33 pp.
[18] Ministry of Housing and Local Government, "Pollution of Water by Tipped Refuse," *Report of Technical Committee on Experimental Disposal of House Refuse in Wet and Dry Pits*, Her Majesty's Stationery Office, London, 1961, 141 pp.
[19] University of Southern California, Sanitary Engineering Research Laboratory, "Investigation of Leaching of Ash Dumps," *Publication 2*, California Pollution Control Board, Sacramento, Calif., 1952, 100 pp.
[20] University of Southern California, Sanitary Engineering Research Laboratory, "Final Report on the Investigation of Leaching of a Sanitary Landfill," *Publication 10*, California Water Pollution Control Board, Sacramento, Calif., 1954, 92 pp.
[21] University of Southern California, Sanitary Engineering Research Laboratory, "Reports on Continuation of an Investigation of Leaching of Rubbish Dumps," *Engineering Center Report Nos. 38-3*, 1955; *46-3*, 1956; *64-3*, 1958; *72-3*, 1960.
[22] Begg, B. A., "Sanitary Landfill—A Bibliography," Civil Engineering Dept., Drexel Inst. of Technology, Philadelphia, Pa., 1967, 20 pp.
[23] Landon, R. A., "Application of Hydrogeology to the Selection of Refuse Disposal Sites," *Ground Water*, Vol. 7, No. 6, 1969, pp. 9-13.
[24] McCormick, J. H., "Chemical Variation of Ground-Water Quality in the Vicinity of a Refuse Landfill," unpublished M.S. Thesis, South Dakota State University, Brookings, S.D., 1966, 59 pp.
[25] Sawinski, R. J., "Ground-Water Quality Variation at a Refuse Landfill," unpublished M.S. Thesis, South Dakota State University, Brookings, S.D., 1966, p. 89.
[26] Werner, D. L., "Preliminary Field Studies Using Earth Resistivity Measurements for Delineating Zones of Contaminated Ground Water," *Ground Water*, Vol. 7, No. 1, 1969, pp. 9-16.
[27] *Water Resources Research Catalog*, Water Resources Scientific Information Center, Vol. 4, 1968.
[28] Midwest Coal Producers Assn., Personal Communication, 1968.

L-D Gold Mine, Wenatchee, Wash.: New Structural Interpretation and Its Utilization in Future Exploration

by Thomas C. Patton and Eric S. Cheney

L-D gold mine is 3 miles south of Wenatchee, central Washington. Recognition of locally mappable conglomerates, sandstones, and shales within the Paleocene (?) Swauk formation led to the discovery that the known epithermal gold mineralization is limited to a previously unknown imbricate thrust zone of unknown displacement cutting the open folds of the area. Hypabyssal intrusions also are most numerous along the trace of the thrust faults. Yakima basalt of Miocene age unconformably overlies the Swauk formation, thrust faults, and the intrusions. The L-D mine is in a northwesterly trending imbricate fault block of nearly vertical strata. Microscopic native gold, electrum, and naumannite occur in quartz veins and as low-grade disseminations in the well-silicified portions of arkosic sandstones. Fault gouge on the "footwall fissure" limits ore to the hanging-wall block of the fault. Epithermal mineralization and alteration are spatially related to the nearby intrusions. Right lateral north-south faults offset the ore a maximum of 300-400 ft along any one fault. From 1949 until January 1967, when the L-D mine closed, 1,036,572 dry tons of ore valued at $14,962,305 and averaging 0.396 oz Au per ton and 0.607 oz Ag per ton were mined. Recognition of the structural control of the mineralization and alteration within the Swauk formation suggests several areas within and outside of the mine that warrant further exploration. For example, the high-angle faults, imbricate thrusts, and the intrusions of this area are on strike with similar features along the major Entiat fault zone 10 miles to the northwest.

The L-D gold mine (previously called Squilchuck, Wenatchee, Golden King, Gold King, and Lovitt) is located in Squilchuck Canyon about three miles south of Wenatchee, Chelan County, Wash. (Fig. 1) on the eastern edge of the Cascade Mountains. The major stratigraphic unit in the area is the nonmarine early Tertiary Swauk formation, which is predominantly composed of arkosic sandstone. The lack of laterally persistent units and the paucity of outcrops heretofore have precluded all but the grossest subdivision of the Swauk.[1] As a result, the true significance of the open folds in the Wenatchee area was not recognized, and although the geology within the mine was known,[2] the structural setting of the mine was virtually unknown.

T. C. PATTON and E. S. CHENEY, Member AIME, are with University of Washington, Seattle, Wash. TP 701203. Manuscript, Jan. 19, 1970. Discussion of this paper, submitted in duplicate prior to June 15, 1971, will appear in SME Transactions, September 1971, and in AIME Transactions, 1971, Vol. 250.

During the present investigation, several locally mappable units were discovered within the Swauk which, in conjunction with mine maps, indicate an imbricate thrust zone. The epithermal gold mineralization, most of the hypabyssal intrusions, and the zones of hydrothermal alteration are located within or near this thrust zone. The purpose of this paper is to: (1) to describe this structural setting, rather than the detailed mine geology already presented by Lovitt and Skerl,[2] and (2) to suggest that from an exploration standpoint, this structural setting may be repeated in areas inside and outside of the mine area.

Stratigraphy and Structure of the Swauk Formation

General: The Swauk formation contains three distinct lithologies. Typical Swauk sandstone is gray on fresh surfaces, poorly sorted, weathers tan, and is crossbedded; it consists of 40-60% quartz, 20-40% feldspar, and up to 10% muscovite and biotite.[3] The typical shale is gray to dark brown, very soft, and interbedded with silty sandstones; sharp contacts exist between the

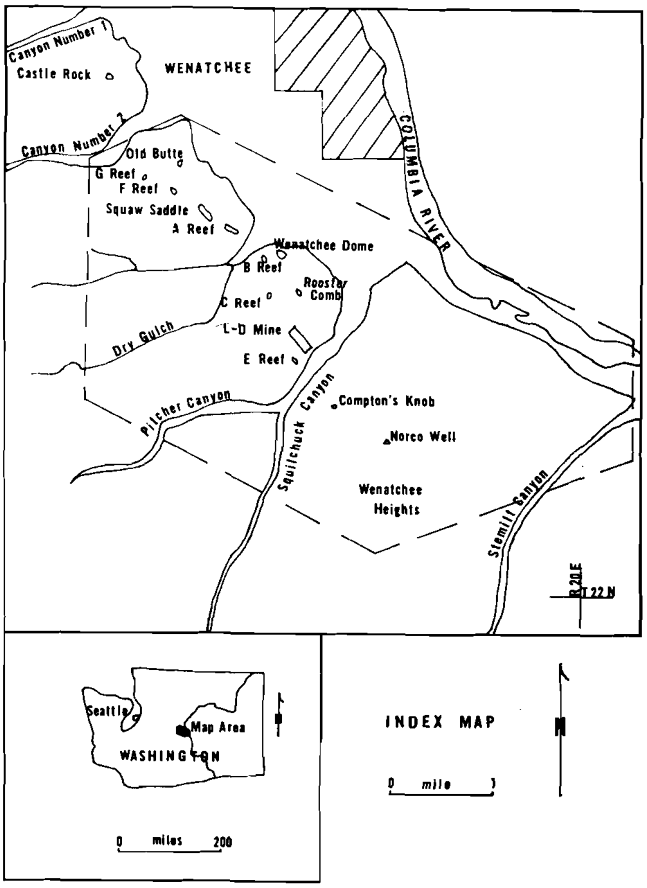

Fig. 1—Index map. Area of Fig. 2 is outlined by dashed lines. Area of Fig. 4 is outlined by the solid rectangle.

sandstone and shale layers. Coarse conglomerates are the least common rock type.

Numerous leaf and wood fragments, thin coal beds, and the absence of marine fossils, together with crossbedding in poorly sorted material, scour and fill, intraformational breccias, lack of laterally persistent beds, and the coarse, angular arkosic sandstones indicate that the Swauk is nonmarine. Fossil leaves from various parts of the formation throughout the Cascade Mountains are reported to range in age from Late Cretaceous to early Eocene.[1,4-6]

Mappable Units: At the confluence of Pitcher and Squilchuck canyons is a distinctive 420-ft stratigraphic sequence within the Swauk (see Fig. 2). Lignite and underlying clay at the base of the exposed beds are overlain by about 100 ft of interbedded purple and gray shale and arkosic sandstone. Gray shales predominate in the lower part of the sequence. Overlying the shale sequence are about 200 ft of medium-grained, massive sandstone containing 90 to 95% quartz; this sandstone is currently being used as a source of foundry sand. Successively above the massive sandstone are 70 ft of purple shale; 20 ft of thin-bedded, brown, arkosic sandstone; and 30 ft of white pebble conglomerate. The pebble conglomerate is composed of subrounded, medium to coarse pebbles of quartz, andesite, and black chert in a sandy arkosic groundmass.

At least 200 ft of distinctive conglomerate are exposed in the main workings of the L-D mine. Here and on the southwestern side of Rooster Comb, the conglomerate consists of large, rusty stained cobbles and small boulders of andesite, quartz, and minor biotitic gneiss. At B Reef,* the number of gneissic clasts is greater and the size of all the clasts is smaller.

* A reef in the local usage, is any silicified portion of the Swauk formation.

About 100 ft of conglomerate crop out along the western side of Stemilt Canyon. Texturally and lithologically, this conglomerate is strikingly similar to the conglomerate at the mine. Because it is unconformably overlain by 75 to 100 ft of sandstone, the original thickness of the conglomerate in Stemilt Canyon cannot be determined. The original thickness of the overlying sandstone cannot be determined because it, in turn, is unconformably overlain by Miocene Yakima basalt.

Structure and Correlation: The distinctive sequence at the junction of Pitcher and Squilchuck Canyons is restricted to the fault-bounded Pitcher syncline (Fig. 2). Steep faults are well-exposed in the workings of the L-D mine.[2,7-8] Crossbedding in associated sandstones demonstrate that the cobble conglomerate in the footwall block is slightly overturned; therefore the easternmost premineralization fault in the mine, the so-called "footwall fissure" (Fig. 4), is a reverse fault. The decrease in dip of this fault with depth suggests that it is part of an imbricate thrust zone (see Fig. 4). The presence of steeply dipping strata as far northwest as Canyon Number Two indicates that the faults continue at least that far.

On the southern side of Dry Gulch, steeply dipping units crop out above a 300-ft covered interval below which are relatively flat lying beds of the southwestern limb of the Pitcher syncline; these dips are suggestive of a second thrust fault within the covered interval. In the divide between the northern and southern forks of Dry Gulch, minor silicification coincides with the termination of the mappable units of the Pitcher syncline. A few steep dips, silicification, and known faulting at G Reef suggest that faults underlie the divide between Dry Gulch and Canyon Number Two.

The angular discordance between the cobble conglomerate and the massive sandstone on the western side of Stemilt Canyon might be interpreted as a southeastward, up-dip extension of the nearly flat basal portion of the imbricate thrust zone. However, crossbedding along the contact, the inclusion of cobbles from the underlying conglomerate in the basal part of the massive sandstone, and the absence of recognizable shearing along most of the contact, support Chappell's contention[9] that this is an angular unconformity.

Correlation of the conglomerates at Stemilt Canyon and the mine is hindered by facies changes and structural complexities. The cobble conglomerate in Stemilt Canyon is on the southwestern limb of the northwesterly plunging Stemilt anticline but is not present on the northeastern limb; the conglomerate may be correlative with pebbly sandstones on the northeastern limb. Because the conglomerate north of the L-D mine is the oldest unit exposed in that area, whereas the conglomerate in Stemilt Canyon is the youngest unit below the unconformity, the presumed correlation of these two strikingly similar conglomerates is difficult to prove. Because the Stemilt anticline plunges to the northwest, the massive sandstone unconformably overlying the conglomerate in Stemilt Canyon need not have been deposited upon either the conglomerate or the overlying strata in the area northeast of the mine.

Couch[10] and Wilson and others[11] noted the lithologic similarity between the massive quartz sandstones in the Pitcher syncline and above the unconformity in Stemilt Canyon. However, sandstone is such a common lithology in the area that correlation of these two units must be regarded as speculative.

Steeply dipping beds on the bluffs above the Columbia River (Fig. 2) may be caused by imbricate thrust faulting or a southeastward extension of the regional high-angle faults of the Entiat fault zone to the northwest (Fig. 3). In 1933-34, the Northwest Oil Research Corp. (NORCO) drilled a 4903-ft well on Wenatchee Heights through 336 ft of Yakima basalt into the Swauk formation and rhyolitic intrusive rocks.[12] Therefore, south of the above-mentioned high-angle faults, the Swauk could be at least 3000 ft thick, if the section is not repeated by thrust faults. Northeast of the Columbia River, on the northern side of the high-angle fault, the thickness of the Swauk is about 1200 ft.[13]

Post-Swauk Intrusions

General Statement: The hypabyssal intrusions within the Swauk[14] form the aligned, jagged spires northwest of the mine: Squaw Saddle, Old Butte, and the narrow rib adjacent to C Reef (Figs. 1 and 2). Wenatchee Dome and Rooster Comb are ¼ mile northeast of the aligned intrusions. Less conspicuous sills and dikes increase in number toward the center of the Twin Peaks andesitic-gabbroic igneous complex[9,15] northwest of the map area.

Petrology and Petrography: Rooster Comb and the Wenatchee Dome are porphyritic biotitic dacites[9,16] and are more siliceous than the other intrusions in the area. Wenatchee Dome has exfoliation sheets, with flow banding parallel to jointing, dipping 25° to 55° away from a common center. Both Wenatchee Dome and Rooster Comb contain igneous breccias, spherulites, and discontinuous zones of perlite along their contacts.[9,12] "Rhyolite" and perlite were encountered in the NORCO well on Wenatchee Heights between depths of 678 to 940 and 1060 to 1360 ft.[12]

The central part of Squaw Saddle is a porphyritic hypersthene basalt; the glassy, olive-green border phase is a more sodic hornblende-pyroxene andesite.[9] The composition of the narrow intrusion adjacent to C Reef is very similar to the border phase of Squaw Saddle. Old Butte consists of both nonglassy, porphyritic andesite and an "olive-green dull-to resinous-lustered glassy andesite . . . whose percentage of glass appears to be greater than in similar rock at Squaw Saddle."[12]

The igneous rocks intrude the Swauk sandstone but apparently do not intrude the overlying Miocene Yakima basalt. All the foregoing andesitic rocks are within the area bounded by thrust faults. The aligned andesitic intrusions and the intrusion adjacent to C Reef have very prominent, steeply dipping joints parallel to the bedding of the adjacent Swauk sandstone; this suggests that the intrusions within the thrust zone may have been emplaced during the last phases of faulting and associated folding. Because some folding of the Swauk preceded the eruption of the middle Eocene Teanaway basalt south of Mount Stuart,[17] the intrusions may possibly be pre-middle Eocene.

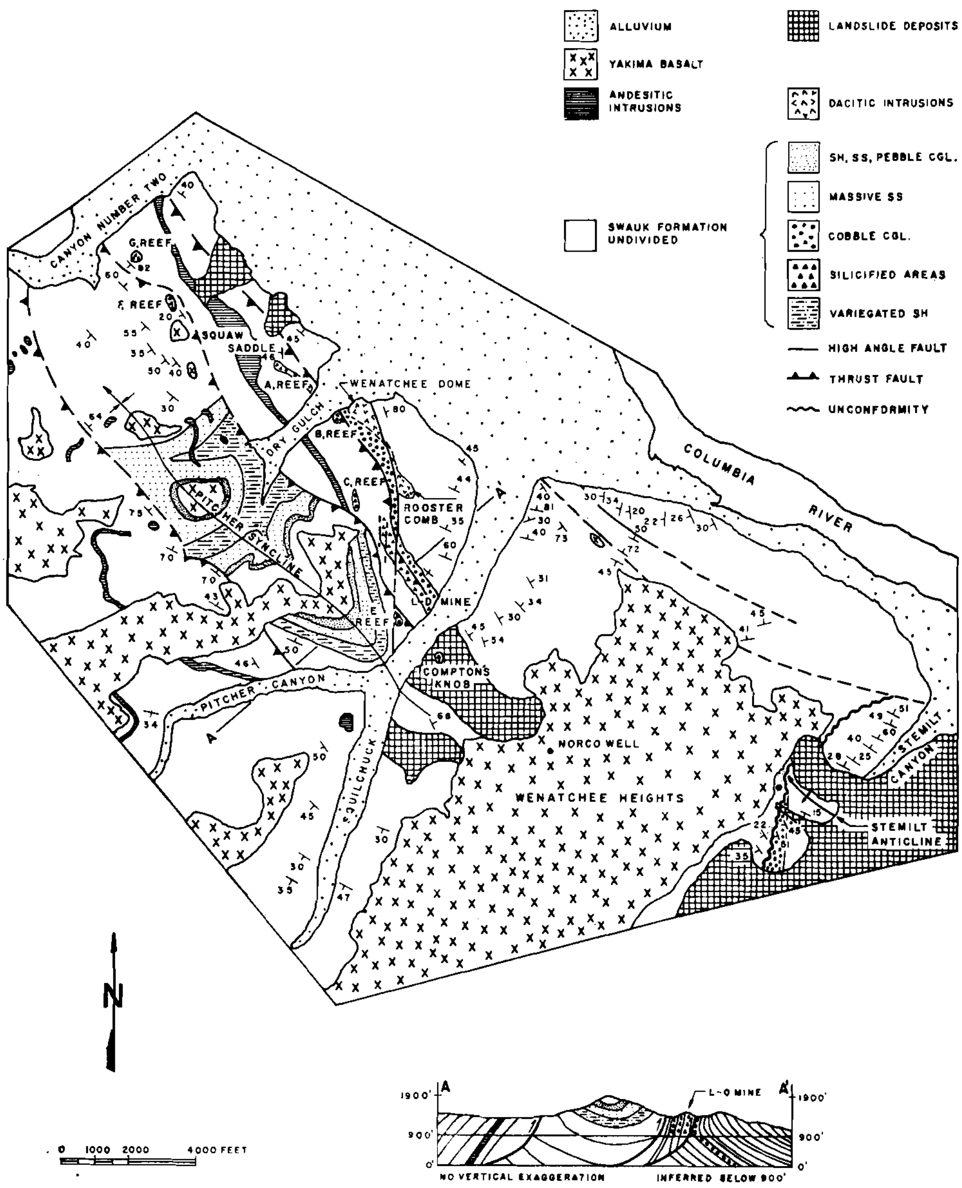

Fig. 2—Geologic map of the L-D mine area.

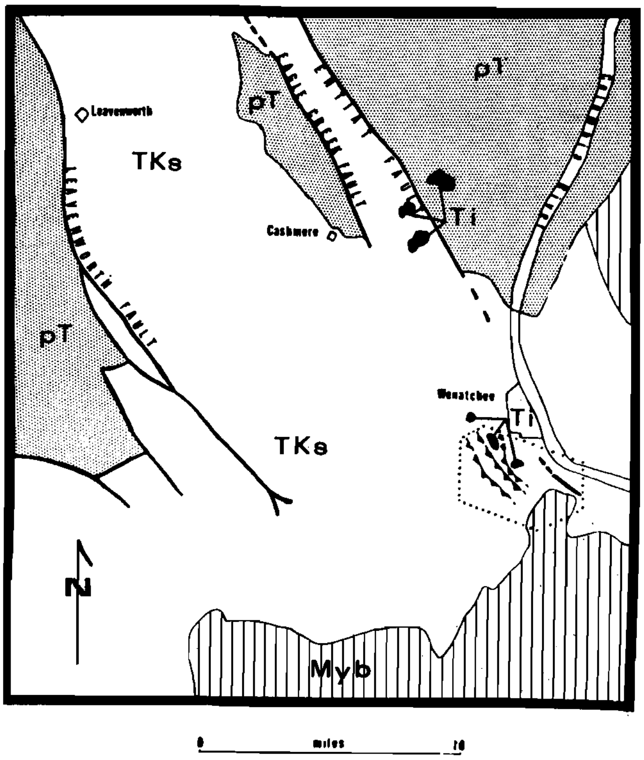

Fig. 3—Regional geologic map. Area of Fig. 2 is outlined by dotted line. After Alexander[8] and Willis.[24] Myb, Yakima basalt; Ti, tertiary intrusions; TKs, Swauk formation; pT, pre-Tertiary igneous and metamorphic rocks. Line with triangles, thrust faults; line without solid triangles, high-angle faults.

ECONOMIC GEOLOGY

History: Lovitt and McDowall[7] point out that prior to 1949, the discouraging economic evaluation of the L-D property was based on the assumption that the ore body was a large, low-grade deposit averaging $3.50-4.00 per ton. With selective underground mining, the ore averaged well over $20 per ton during the last half of 1949 and continued to produce profitably through 1966. As late as 1966, the L-D was the 6th largest gold mine and 13th largest gold producer in the United States. According to E. H. Lovitt,[18] 1,036,572 dry tons of ore valued at $14,962,305 and averaging 0.396 oz. Au per ton and 0.607 oz. Ag per ton were mined from 1949 until the mine closed in January 1967.

Ore has been extracted from the L-D mine between elevations of 850 and 1600 ft, and diamond drilling has shown gold values down to the 750-ft level. Significant development work has been done at B Reef. Exploration adits at Compton's Knob, and A, C, F, and G Reefs did not encounter ore. At E Reef diamond drilling revealed only minor gold values.

Ore Mineralogy and Hydrothermal Alteration: Guilbert's comprehensive study[19] of the fine-grained to microscopic ore minerals revealed gold, electrum, naumannite (Ag_2Se), and minor aguilarite ($Ag_2Se \cdot Ag_2S$), an assemblage which has only been found elsewhere in the United States at Republic, Wash.[20] Guilbert's study showed that: (1) ore minerals are found both in quartz veinlets and silicified arkosic sandstone; (2) the ore minerals usually range in size from 1 to 80μ in diam; and (3) brecciation, absence of mylonite, and breaks around grains indicate that the mineralized fractures were tensional openings.

Guilbert distinguished three periods of silicification: (1) early pervasive silica, (2) milky fine-grained vuggy vein quartz, and (3) late coarse-grained clear coxcomb vein quartz. Other evidence supports Guilbert's identification of three periods of silicification. In the Wenatchee area, Swauk sandstone is normally poorly cemented; therefore, only pervasive silicification could increase the competency sufficiently to permit fracturing and the formation of ore-bearing quartz veins. A third period of silicification produced barren veins that offset ore-bearing veins. On the southwestern side of Canyon Number Two, clear coxcomb vein quartz corresponding to Guilbert's late veins, cuts the andesitic intrusions.

A close spatial relationship exists between areas of hydrothermal alteration, the steeply dipping Swauk sandstones within the thrust zone, and the intrusions aligned northwest of the L-D mine. The most obvious example of hydrothermal alteration is at the L-D mine on the western side of Squilchuck Canyon: a jagged cliff of tan, silicified arkosic rocks[9,10,21] is crisscrossed by quartz veins. Early miners called this "bastard granite."[7] Intense silicification and brecciation occur at Compton's Knob, and A, B, C, E, F, and G Reefs (Fig. 2). Coombs[16] noted hydrothermal alteration at Wenatchee Dome, and Huntting[13] reported silicification at Rooster Comb and in the NORCO well between depths of 715 to 815 ft.

Structural Control of Ore: Lovitt and Skerl[2] inferred that the hydrothermally altered mine rocks were folded, faulted, and subsequently formed a monadnock against which the younger Swauk formation was deposited. However, the dissimilar stratigraphy of each of the antiformal limbs on either side of the mine rocks (Fig. 2), the overturned and vertical beds that decrease in dip north-eastward away from the mine, and high-angle faulting in the mine and elsewhere make this hypothesis untenable. The steeply dipping mine rocks are most probably an imbricate thrust block within the Swauk formation (Fig. 2 and 4).

The chief structural control of ore is the "footwall fissure," a zone of shaly lustrous, soft, black fault gouge (Fig. 4). It dips steeply southwesterly, has eastern and western strands which apparently merge at depth, and contains many angular sandstone fragments. Ore values and silicification are limited to the hanging-wall block of the western strand. The cobble conglomerate on the footwall side of the fault dips steeply to the southwest. The same relationship exists at B Reef: the ore is on the hanging-wall side of the footwall fissure and the conglomerate is on the footwall side. Because the conglomerate is not present at A Reef, both it and the associated eastern strand may have been offset northeast of A Reef by right-lateral faults similar to those in the mine.

Lovitt and Skerl[2] note that the southeastern section of the mine has a "fairly regular pattern of major veins . . . that have been mined as separate entities, but the bulk of the tonnage produced is from zones of veins and veinlets. . . ." They also noted that northward dipping veins, which correspond to the second period of silicification, carried most of the gold. This regular system of fractures and most intense hydrothermal alteration occurs where two imbricate thrust faults converge east of the easternmost north-south fault shown in Figs. 2 and 4.

These steeply dipping north-south faults offset the ore-bearing structures as much as 400 ft to the north, creating several blocks within the mine. Lovitt and Skerl[2] mapped more than ten north-south faults. As one passes northwestward from Block I, through Block II, to Block III, the dips of the strands of the footwall fissure diminish, the northwesterly dip of the major ore-bearing veinlets decrease, and the NE-SW width of the mineralized area on a given level increases; these phenomena could be explained if the western block on each north-south fault was uplifted, so that successively deeper portions of the imbricate fault block occur on a given level in each successive western block.

Conclusions and Recommendations for Future Exploration

Under more favorable economic conditions, the L-D mine might reopen. Perhaps most of the silicified areas would show appreciable gold values if sufficient money were available to test them extensively. The following geologic environments and areas are worthy of further exploration.

1) Any steeply dipping, silicified sandstone close to an intrusion merits investigation.

2) The presence of gold at A and B Reef suggests that exploration between these two silicified areas might reveal gold mineralization beneath the valley fill.

3) If the blocks west of the main north-south fault were uplifted as suggested, previous exploration in the mine for steeply dipping ore bodies may have missed some ore.

4) Silicification at Compton's Knob on the southeastern side of Squilchuck Canyon and the presence of thrust faults at the L-D mine on the northwestern side of the canyon suggest that mineralization may extend under the Canyon.

5) The structural complexities on each side of the Squilchuck-Stemilt divide (Wenatchee Heights) capped by Yakima Basalt, and the silicification and intrusions encountered beneath the basalt cap by the NORCO well have been noted previously. Pieces of shaly fault gouge occur in the cuttings from the well. It may well be significant that assays of two samples of this material obtained by E. A. Magill of the U.S. Bureau of Mines were 0.697 oz. Ag per ton and no gold at 590 to 600 ft and neither gold nor silver at 653 to 669 ft. Rhyolite at 905 to 923 ft assays 0.016 to 0.048 oz. Au per ton and no silver.

6) The epithermal gold-quartz veins of the Republic district of north-central Washington[20,22] have nearly the same mineralogy and are approximately the same age as the L-D ores. The ores of both districts are spatially, and presumably genetically, related to large regional faults. Therefore, future regional exploration should be directed northwestward along the regional Entiat fault zone shown in Fig. 3, particularly the area around the rhyolitic and andesitic Tertiary intrusions[23] in the Swauk formation east of Cashmere. Southeast of the L-D mine favorable areas may lie beneath the Miocene Yakima basalt.

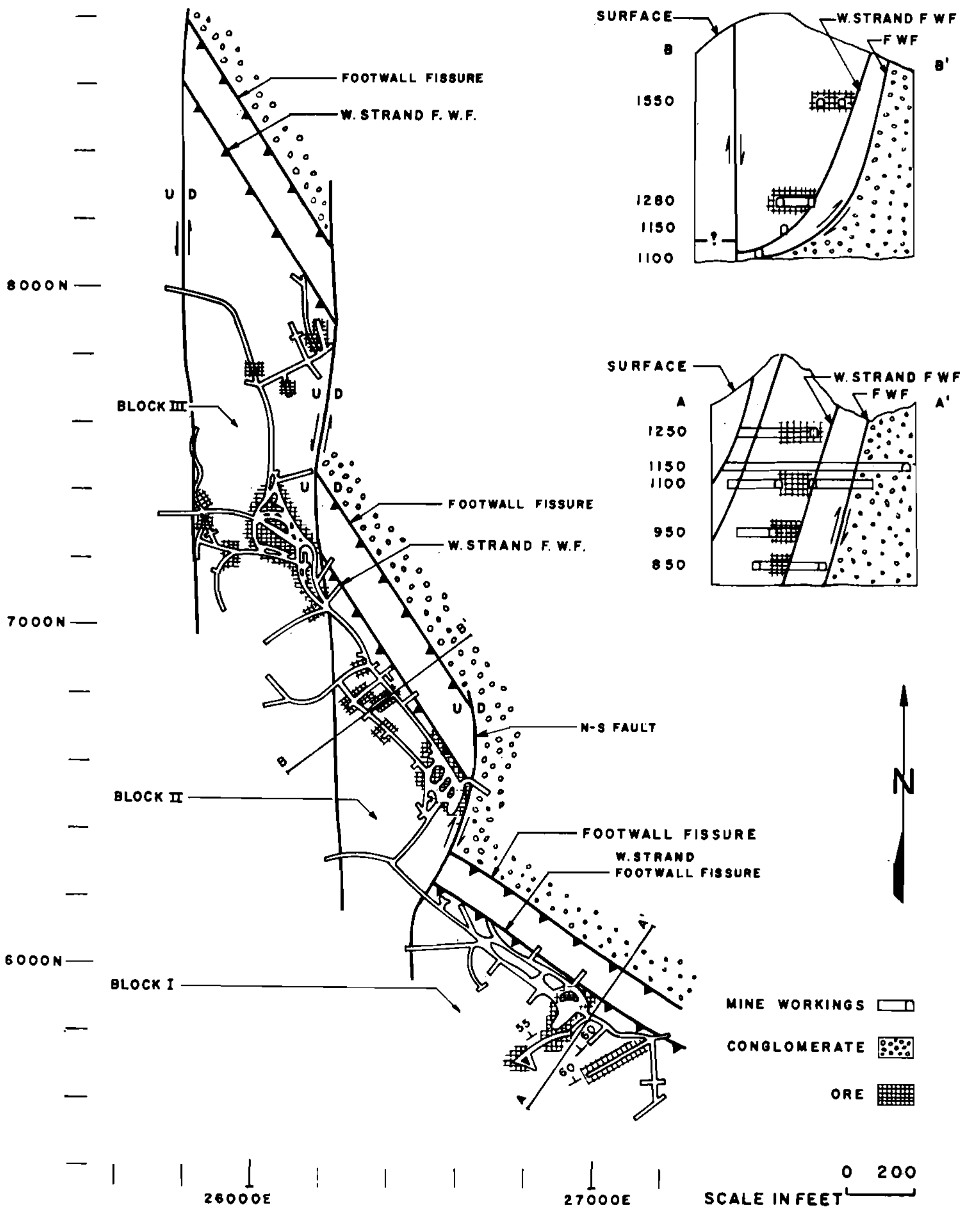

Fig. 4—Generalized geology of the L-D mine: 1250 level and cross sections; see Fig. 1 for location. The northwesterly dipping ores in the crosscuts of Block I and Block II are the veins.

Acknowledgments

We would like to thank E. H. Lovitt, principal owner and general manager of the L-D mine, for financing the investigation, and E. B. McKee, M. T. Huntting, T. V. Livingston, W. S. Moen, C. P. Purdy, and J. W. Trammell for critically reading earlier drafts of this paper

References

[1] Young, R. E., "Geology of the Swauk Formation in the Leavenworth, Washington, Area," Unpublished undergraduate thesis, University of Washington, Seattle, 1963, 45 pp.
[2] Lovitt, E. H., and Skerl, A. C., "Geology of the Lovitt Gold Mine, Wenatchee, Washington," *Mining Engineering*, Vol. 10, No. 9, Sep. 1958, pp. 963-966.
[3] Industrial Consultants, "Economic Feasibility of Silica Sand Processing and Related Manufacturing Operations in Chelan County, Washington," Economic Development Administration, Technical Assistance Project, U.S. Dept. of Commerce, 1966, 103 pp.
[4] Rector, R. J., "Geology of the East Half of the Swauk Creek Mining District," Unpublished M.S. thesis, University of Washington, Seattle, 1962, 73 pp.
[5] LaMotte, R. S., "Preliminary Report on Fossil Collection from the Swauk Formation at the University of California," *Geology of the Wenatchee Quadrangle*, Unpublished Ph.D. thesis by W. M. Chappell, University of Washington, Seattle, 1936, pp. 72-76.
[6] Alexander, F., "Stratigraphic and Structural Geology of the Blewett-Swauk Area, Washington," Unpublished M.S. thesis, University of Washington, Seattle, 1956, 64 pp.
[7] Lovitt, E. H., and McDowall, V., "The Gold King Mine," *Western Miner and Oil Review*, Vol. 27, 1954, pp. 37-39.
[8] MacLaren, D. R., et al., "Gold," *Mineral and Water Resources of Washington*, A. E. Weissenborn, ed., Washington Div. of Mines & Geology, Reprint 9, 1966, pp. 82-92.
[9] Chappel, W. M., "Geology of the Wenatchee Quadrangle," Unpublished Ph.D. thesis, University of Washington, Seattle, 1936, 249 pp.
[10] Couch, A. H., "Silica Sands of Washington," Unpublished M.S. thesis, University of Washington, Seattle, 1935, 98 pp.
[11] Wilson, H., Skinner, K. G., and Couch, A. H., "Silica Sands of Washington," *Engineering Experiment Station Bulletin*, Vol. 108, 1942, 76 pp.
[12] Huntting, M. T., "Perlite and Other Volcanic Glass Occurrences in Washington," *Report of Investigations*, Washington, Div. of Mines & Geology, Vol. 17, 1949, pp. 1-77.
[13] Coombs, H. A., Personal Communication, 1967.
[14] Smith, G. O., and Calkins, F. C., "A Geological Reconnaissance Across the Cascade Range Near the Forty-Ninth Parallel," *Bulletin*, U.S. Geological Survey, Vol. 235, 1904, pp. 3-103.
[15] Bayley, E. P., "Bedrock Geology of Twin Peaks Area, An Intrusive Complex Near Wenatchee, Washington," Unpublished M.S. thesis, University of Washington, Seattle, 1965, 47 pp.
[16] Coombs, H. A., "Spherulitic Breccias in a Dome Near Wenatchee, Washington," *American Mineralogist*, Vol. 37, 1952, pp. 197-206.
[17] Smith, G. O., "Mount Stuart Folio (No. 106)," *Atlas*, U.S. Geological Survey, 1904, 10 pp.
[18] Lovitt, E. H., Personal Communication, 1969.
[19] Guilbert, J. M., "Report on Selected Specimens from the Gold King Mine, Wenatchee, Washington," Unpublished report for Day Mines, Inc., Wallace, Idaho, 1963, 27 pp.
[20] Full, R. P., and Grantham, R. M., "Ore Deposits of the Republic Mining District, Ferry County, Washington," *Ore Deposits of the United States, 1933-1967*, J. D. Ridge, ed., AIME, New York, 1968, pp. 1481-1494.
[21] Coombs, H. A., "Granitization in the Swauk Arkose Near Wenatchee, Washington," *American Journal of Science*, Vol. 248, 1950, pp. 369-377.
[22] Wright, L. D., "Geologic Relations and New Ore Bodies of the Republic District, Washington," *Trans. AIME*, Vol. 178, 1949, pp. 264-282.
[23] Waters, A. C., "A Petrologic and Structural Study of the Swakane Gneiss, Entiat Mountains, Washington," *Journal of Geology*, Vol. 40, 1932, pp. 604-633.
[24] Willis, C. L., "The Chiwaukum Graben, A Major Structure of Central Washington," *American Journal of Science*, Vol. 251, 1953, pp. 789-797.

Ground-Water Reclamation by Selective Pumping

by Leslie G. McMillion

A field project to develop and demonstrate a method for alleviating problems of highly mineralized ground water where they occur as isolated zones or pockets in fresh-water aquifers is being conducted in the Ogallala aquifer of eastern New Mexico by the Robert S. Kerr Water Research Center. Removal of contaminated water is by a large-capacity well and the pumped poor-quality water is used locally for secondary recovery of oil. Benefits of the operation are threefold in that the aquifer is being reclaimed for future fresh-water production, contaminated water is being used beneficially, and fresh water which otherwise would have been used for waterflooding is available for other purposes. Ground-water quality in the site has improved markedly after two years of operation.

Use of water in the arid and semiarid Southwest has grown so rapidly that demands in many localities far exceed available supplies. In the High Plains region of New Mexico, Oklahoma, and Texas, the only large sources of water are underground reservoirs, being depleted at an alarming rate.

In some parts of this region, the aquifers contain pockets of highly mineralized waters; and the mineralized waters in some of them have started spreading in response to the drawdown effects of pumping wells. The aquifers of this region are primarily composed of sand and gravel beds; any cleanup by natural processes will require many tens or even hundreds of years.

L. G. McMILLION is Research Geologist, Robert S. Kerr Water Research Center, Ada, Okla.

SME Preprint 70AG55, AIME Annual Meeting, Denver, Colo., February 1970. Manuscript, Nov. 5, 1969. Discussion of this paper submitted in duplicate prior to June 15, 1971, will appear in SME Transactions, September 1971, and in AIME Transactions, 1971, Vol. 250.

Most of these pockets of highly mineralized water were caused by oil-field brines seeping downward from earthen disposal pits. Thousands of these pits were in use in the region until only a few years ago when they were prohibited by the oil regulatory agencies of the respective states.

The resulting areas of poor quality water are serious enough to warrant much corrective attention. Correction will involve one or more of three approaches:

1) Restrict the pumping of fresh water in the zones where the drawdown of the pumping well will significantly influence the movement of the contaminant.

2) Remove the highly mineralized water entirely from the affected area.

3) Develop and pump the poor-quality water in such a manner that its movement is held in check, even though only a part of the contaminant is actually removed.

The principal hurdle to overcome in applying methods 2 or 3 is financing of the operations, since there are very