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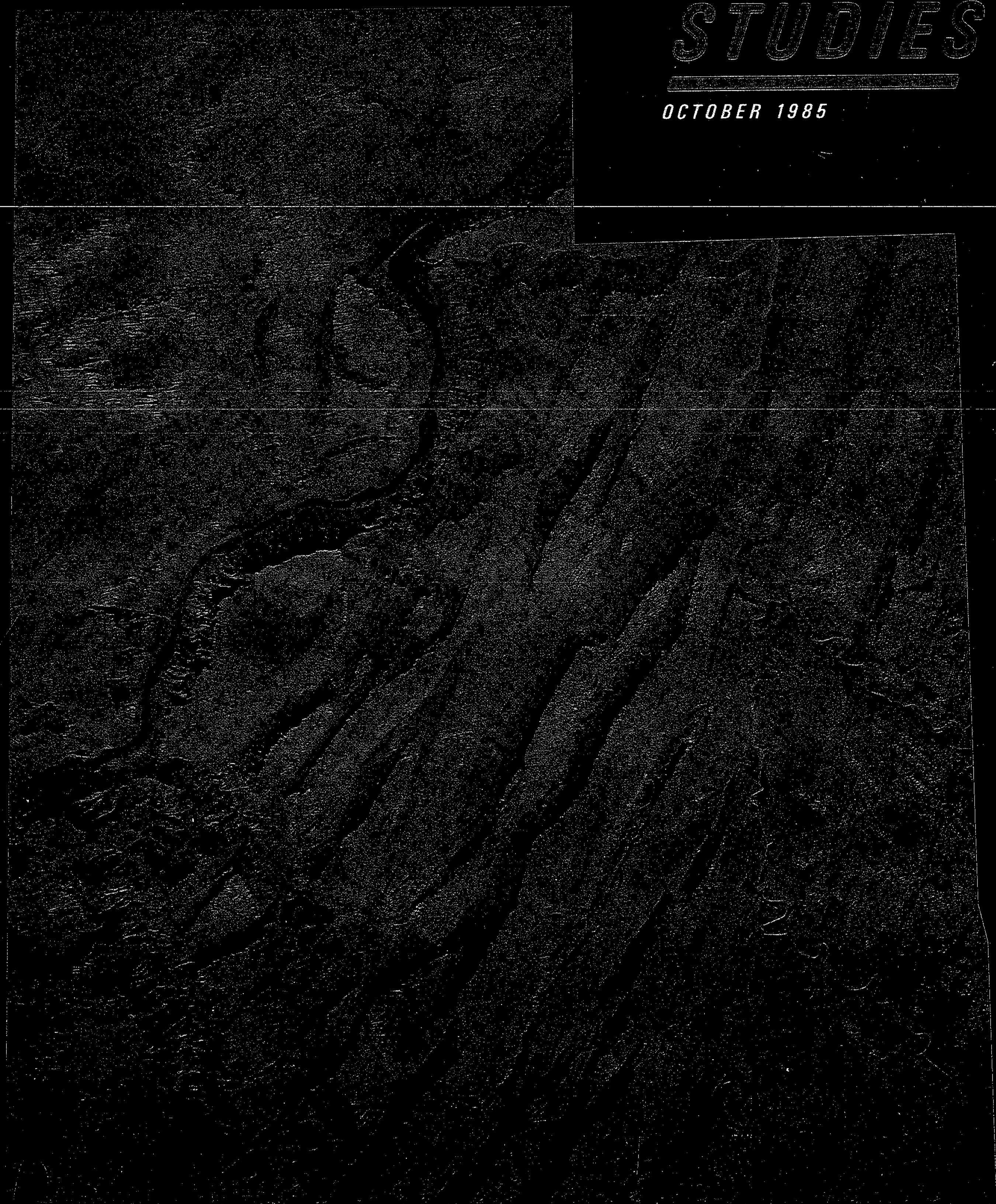

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CONTENTS

THE GLORY OF GOD IS INTELLIGENCE

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CONTENTS

Upper Proterozoic Glacial-marine and Subglacial Deposits at Little Mountain, Utah

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ABSTRACT

A sequence as much as 1,000 m thick of slaty argillite, diabase, and glacially derived diamictite of Late Proterozoic age is well exposed and easily accessible at Little Mountain on the shore of the Great Salt Lake near Ogden, Utah. The rocks occur in the lower part of a westward-thickening miogeoclinal wedge that was folded and thrust eastward over the continental platform during Cretaceous and early Tertiary time. The diamictite is relatively massive and texturally homogeneous, and is composed of rounded, dominantly granitic clasts, as large as boulders, dispersed in a gritty, feldspathic matrix. It is thought to have been deposited from floating ice, and in part from grounded ice, as a continental ice sheet advanced westward into a marine basin.

INTRODUCTION

The geology of Little Mountain, approximately 25 km west of Ogden, Utah, was first described by Blackwelder (1932), who noticed the distinctive boulder-bearing black diamictite "from the window of a passing train." Similar rocks of Late Proterozoic age[1] occur in many parts of northern Utah and southeastern Idaho, and over the past 50 years these deposits have been ascribed to both glacial and nonglacial processes (Crittenden and others 1983). This short article is intended to provide an up-to-date description and interpretation of the diamictite outcrops at Little Mountain, which are among the most accessible in Utah.

DESCRIPTION OF SEQUENCE AT LITTLE MOUNTAIN

Little Mountain is underlain largely by diamictite (fig. 1). The base is exposed only at the southern end, where a section of diamictite approximately 400 m thick overlies about 120 m of diabase, largely intrusive, and about 400 m of slaty argillite (fig. 2). Thicknesses are uncertain, because the diamictite is relatively massive and all units are internally folded (as shown diagrammatically in the cross section of figure 1).

[1]Late (Upper) Proterozoic is used in the sense recommended by Harrison and Peterman (1980, 1982) for the interval between 900 and 570 Ma.

SLATE UNIT

The slate unit, the lowest exposed at Little Mountain (fig. 2), consists predominantly of gray, locally pyritic, lineated slaty argillite with kink bands (fig. 3). Primary laminae are defined by differences in hue and are intersected obliquely by the cleavage. Bed thicknesses range from less than 1 mm to several centimeters, and the thickness of individual laminae is locally variable. The apparent absence of variation in grain size between laminae and especially the absence of well-defined couplets suggest that the slates are not clastic varves, an interpretation proposed by Blackwelder (1932). Subordinate interbeds of fine-grained quartzose sandstone are commonly laminated or cross-laminated, and are bounded by sharp, planar contacts. Sandstone as thick as several meters locally occupies broad channels. A thin, lenticular, poorly exposed bed of gray clastic dolomite occurs near the top of the slate unit (d in fig. 1).

VOLCANIC UNIT

The volcanic unit consists of massive diabase (probably intrusive) and subordinate pillow lava (fig. 4). Good examples of the latter occur near the circular tanks immediately south of the road inside the outer perimeter of the Hill Air Force Base annex. Pillow rims are vesicular and interpillow material is inferred to be mainly aquagene tuff. The diabase is composed of saussuritized laths of plagioclase in a felted groundmass chlorite, with calcite and minor epidote. Trace element data are consistent with intraplate volcanism (Harper and Link 1985), corroborating the interpretation of the formation of Perry Canyon as a syn-rift deposit (Crittenden and others 1983).

DIAMICTITE UNIT

The uppermost unit exposed at Little Mountain consists of black, locally pyritic diamictite (fig. 5), in which

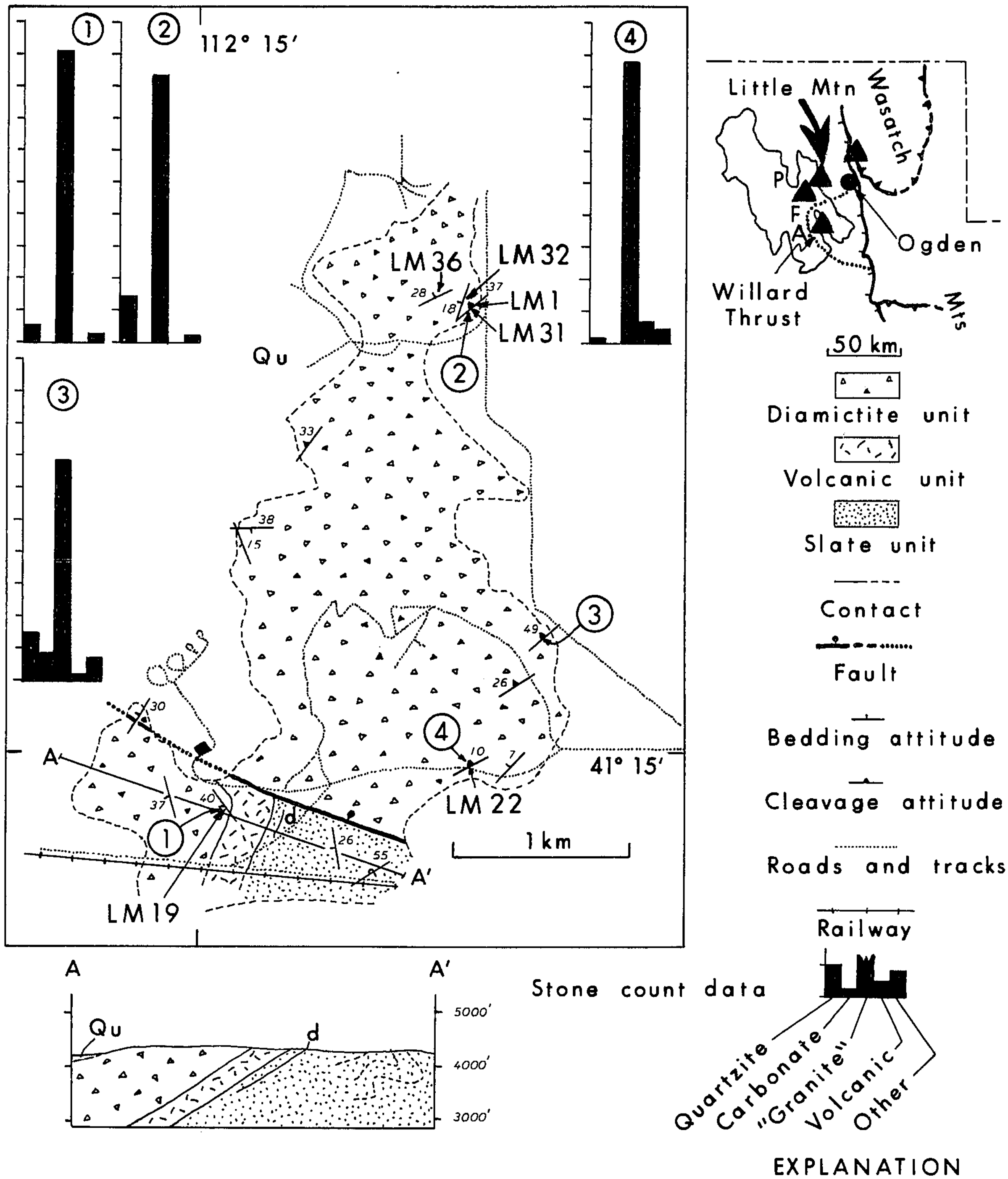
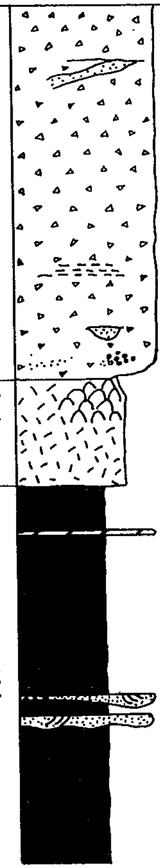


FIGURE 1.—*Geological map and cross section of Little Mountain, in parts of the Plain City SW, Willard Spur, Fremont Island, and Ogden Bay Quadrangles, Utah (from Blick 1979). The diamictite, volcanic, and slate units are informal subdivisions of the formation of Perry Canyon of Sorensen and Crittenden (1976). Symbols: d, dolomite; Qu, undifferentiated Quaternary sediments. Sample localities and histograms of clast count data (see tables 1 to 3). Index map: P, Promontory Range; F, Fremont Island; A, Antelope Island; filled triangles represent diamictite localities.*



Informal Division	Thickness (m)	Description	Interpretation
DIAMICTITE UNIT	~400	Black diamictite, generally massive and homogeneous, but locally containing clots, wisps, pebble layers, interbeds and channels, particularly in the lower part. One bed overlies an erosion surface. Dominated by granitic detritus.	Glacial-marine diamictite and perhaps waterlain tillite at base, passing upward into tillite that may have accumulated beneath a grounded ice sheet.
VOLCANIC UNIT	~120	Diabase, for the most part massive, but locally containing pillow structures.	Shallow-level sills, intruded under a thin cover of wet sediment and extruded lava.
SLATE UNIT	~400	Slaty argillite and laminated slaty argillite, with cross-laminated beds and lenses of sandstone. Thin lenticular bed of dolomite.	Marine deposit (not clastic varves).

FIGURE 2.—*Informal subdivisions and interpretation of the formation of Perry Canyon at Little Mountain. See text for additional explanation.*

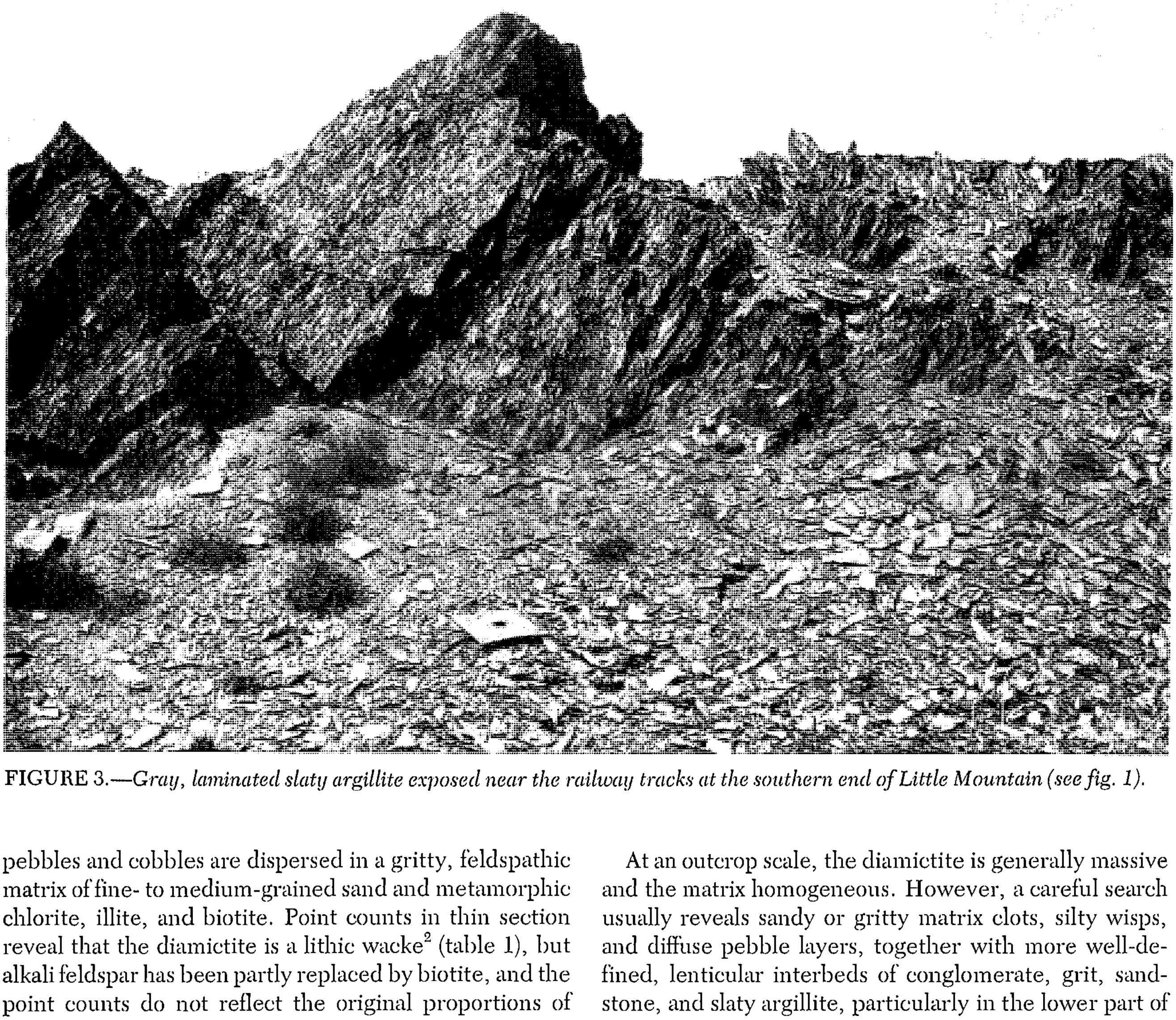


FIGURE 3.—*Gray, laminated slaty argillite exposed near the railway tracks at the southern end of Little Mountain (see fig. 1).*

pebbles and cobbles are dispersed in a gritty, feldspathic matrix of fine- to medium-grained sand and metamorphic chlorite, illite, and biotite. Point counts in thin section reveal that the diamictite is a lithic wacke[2] (table 1), but alkali feldspar has been partly replaced by biotite, and the point counts do not reflect the original proportions of feldspar grains and rock fragments.

Major element chemistry of diamictite matrix and grit at Little Mountain is compared with the average graywacke of Pettijohn (1963) in table 2. SiO_2, MgO, and MnO of the diamictite samples are similar to average graywacke. A granitic source is suggested by high Al_2O_3 and K_2O and by an average whole rock K_2O/Na_2O ratio of 1.7. The proportion of CaO is variable, but low in most samples of diamictite. Total iron (as FeO) and TiO_2 are high especially in samples with low Na_2O.

[2]A lithic wacke is a sedimentary rock composed of more than 15% matrix grains smaller than 30μm, and in which on a QFR plot of grains larger than 30 μm, R > F and R > 5% of the total (Q = monomineralic quartz and chert lacking a lithic texture; F = single grains of feldspar; R = polymineralic grains or those with a lithic texture; modified from Pettijohn and others 1973; Williams and others 1982).

At an outcrop scale, the diamictite is generally massive and the matrix homogeneous. However, a careful search usually reveals sandy or gritty matrix clots, silty wisps, and diffuse pebble layers, together with more well-defined, lenticular interbeds of conglomerate, grit, sandstone, and slaty argillite, particularly in the lower part of the diamictite unit (figs. 6 and 7).

Clasts larger than 1 cm in the diamictite are predominantly granitic (gneissose, schistose, and unfoliated varieties) and quartzite, with accessory metamorphic, volcanic, and sedimentary rocks, including carbonate (table 3). Among quartzite stones is a rare but distinctive green chromian variety found at many localities in northern Utah (Crittenden and others 1983). The granite and quartzite clasts are for the most part rounded and relatively equidimensional. The largest observed at Little Mountain is 3.4 m in diameter (granite). Clast concentration ranges from relatively sparse to crowded. Some stones are noticeably flattened parallel to the phyllitic cleavage (fig. 5). A few have developed tails.

The lower contact of the diamictite unit is inferred to be relatively conformable and non-erosive, because diabase fragments are rare (table 3, locality 1). On nearby Fre-

FIGURE 4.—*Pillow lava exposed near the circular tanks immediately south of the road inside the outer perimeter of the Hill Air Force Base annex.*

mont Island in the Great Salt Lake (fig. 1), correlative diamictite locally overlies slaty argillite and several tens of meters of pebbly argillite. Condie (1967) termed the contact gradational. Unfortunately, in most places on Fremont Island, this important relationship is obscured by diabase sills (Blick 1979).

REGIONAL GEOLOGIC SETTING

The rocks at Little Mountain occur in the lower part of a westward-thickening miogeoclinal wedge and are correlative with the formation of Perry Canyon mapped by Sorensen and Crittenden (1976) in the Willard thrust plate of the northern Wasatch Mountains (see the index map of fig. 1). On Fremont Island, southwest of Little Mountain, this same stratigraphic unit may be as much as 3,000 m thick (Crittenden and others 1983). As in the northern Wasatch Mountains, the formation of Perry Canyon exposed at Little Mountain and on Fremont Island is allochthonous and was displaced several tens of kilometers to the east during Cretaceous and early Tertiary time by the Willard thrust (Crittenden 1972). In contrast, diamictite on Antelope Island (fig. 1) is autochthonous or parautochthonous and was deposited on the continental platform (Christie-Blick 1983).

INTERPRETATION OF DIAMICTITE UNIT

Recent work by Varney (1976), Blick (1979), Ojakangas and Matsch (1980), Christie-Blick (1983), and Crittenden and others (1983) has provided definitive evidence for Late Proterozoic glaciation in Utah. This evidence consists of (1) thick sections of diamictite containing some angular matrix grains and large lonestones (i.e., isolated stones) of diverse provenance; (2) the occurrence in diamictite of hard stones, including chert, with intersecting scratches and grooves, facets, and rarely a pentagonal flatiron shape (features here attributed to glacial abrasion); (3) the presence in the central Wasatch Mountains of a striated pavement beneath diamictite; and (4) the occurrence in laminites at widely separated localities of lonestones, rarely as large as boulders, together with isolated sand and gravel clots, all of which are thought to have been rafted by ice.

FIGURE 5.—*Relatively crowded pebble-cobble diamictite near the base of the diamictite unit. Note the heterogeneity in clast distribution and the tendency for clasts to be flattened parallel to the phyllitic cleavage.*

At Little Mountain I observed only one stone (quartzite) with possible striae. The apparent lack of striated clasts is probably due to their being dominantly "granite," to subsequent metamorphism, deformation, and weathering, and to poor exposure of original clast surfaces. Stone shape is strongly influenced by internal structure (foliation, fractures, bedding), and at Little Mountain most flat surfaces are probably not facets, contrary to the original interpretation of Blackwelder (1932).

No convincing dropstones (rafted lonestones) have been observed at Little Mountain. However, in the lower part of the formation of Perry Canyon on Fremont Island, isolated quartzite boulders as large as 2.5 m occur in bedded argillite with dispersed granules (Crittenden and others 1983). Heterogeneous diamictite and irregular pods of partially sorted sediment in diffuse contact with surrounding diamictite at Little Mountain may constitute additional evidence for rafting (fig. 7, A and B).

The occurrence of possible dropstones and of turbidites in the formation of Perry Canyon on Fremont Island and of pillow lava at Little Mountain suggests subaqueous deposition for at least the lower part of the diamictite unit. The absence of clastic varves in fine-grained beds suggests marine sedimentation. The depth of water is not known, although it was probably subtidal. Pyrite is common as porphyroblasts, and the interfingering of black diamictite and mudstone with olive-drab graywacke and siltstone (northern Wasatch Mountains; Crittenden and others 1983) indicates that the occurrence of iron sulphide probably mimics its original distribution in the sediment in response to sporadically reducing conditions.

The lowermost part of the diamictite unit is thought to have accumulated in a glacial-marine environment from ice-rafted detritus and fine material suspended in the water column. Some diamictite may be waterlain tillite (i.e., subglacial meltout or flow tillite derived from a partly buoyant glacier or ice sheet with a subaqueous ice margin; Dreimanis 1979). Evidence favoring such interpretations consists of (1) the transitional contact between diamictite and underlying argillite on Fremont Island; (2) the preferential occurrence of current-sorted sediment near the base of the diamictite unit at Little Mountain; (3) the occurrence of texturally heterogeneous diamictite (a result of rafting and winnowing); and (4) the fact that basic volcanic rocks, exposed on the sea floor immediately prior to deposition of the first diamictite, are not markedly included as clasts. However, much of the diamictite at Little Mountain is massive, and some may be lodgment tillite, deposited beneath an actively moving glacier as a result of retardation of debris particles or debris-rich ice masses by friction against the glacier bed (see Boulton and Deynoux 1981). Corroborating this interpretation is the observation at the north end of Little Mountain of one diamictite bed overlying an erosion surface that truncates inclined beds of pebbly sandstone and conglomerate (sample locality LM36 in fig. 1).

A few paleocurrents measured in turbidites in the lower part of the Fremont Island section are toward the northwest, but in view of the deformation at that locality, this direction must be regarded as tentative (Crittenden and others 1983). Few data are available for the section exposed at Little Mountain.

In summary, the diamictite at Little Mountain is interpreted to be glacially derived on the basis of evidence best displayed at other localities. It is thought to have been deposited from floating ice and in part from grounded ice that advanced from a granitic basement terrane, exposed to the east, into a marine basin.

ACKNOWLEDGMENTS

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Lamont-Doherty Geological Observatory Contribution No. 3831.

REFERENCES CITED

Blackwelder, E., 1932, An ancient glacial formation in Utah: Journal of Geology, v. 40, p. 289–304.

Blick, N. H., 1979, Stratigraphic, structural, and paleogeographic interpretation of upper Proterozoic glaciogenic rocks in the Sevier orogenic belt, northwestern Utah: Ph.D. dissertation, University of California, Santa Barbara, California, 633p.

Boulton, G. S., and Deynoux, M., 1981, Sedimentation in glacial environments and the identification of tills and tillites in ancient sedimentary sequences: Precambrian Research, v. 15, p. 397–422.

Christie-Blick, N., 1983, Glacial-marine and subglacial sedimentation, Upper Proterozoic Mineral Fork Formation, Utah: In Molnia, B. F.

Table 1. Results of point counts in thin sections of diamictite (LM 19, LM 31, LR 2) and sandstone (LM 32). Sample localities are indicated in figure 1. LR 2 is from Landing Rocks about 1 km southwest of Little Mountain.

Sample	LM 19	LM 31	LR 2	LM 32
Quartz:				
monocrystalline	35.2	20.8	16.0	38.6
polycrystalline	2.4	1.9	0.5	2.3
microcrystalline	—	0.4	—	0.9
Plagioclase	0.6	—	0.4	9.5
Alkali feldspar	0.9	—	—	1.1
Carbonate:				
authigenic	1.8	—	—	1.9
detrital	0.2	0.4	4.4	1.9
Rock fragments:				
granitic	0.4	3.2	0.9	7.4
volcanic	—	0.2	3.6	—
sedimentary	—	0.7	0.2	0.5
metamorphic	—	0.7	—	—
undifferentiated	2.8	1.8	—	—
Muscovite	1.5	—	—	0.3
Biotite	—	4.4	0.5	3.2
Chlorite	—	1.2	—	2.0
Opaque	0.4	1.2	0.9	1.3
Goethite	—	1.1	0.5	1.4
Accessory	—	—	0.2	—
Matrix	53.9	61.6	71.9	27.6
Void	—	0.5	—	—
Total %	100.1	100.1	100.0	99.9
Total points counted	545	567	562	557
Modal grain size	f-m	f-m	f-m	m-c
Q	88.5	76.7	63.5	67.2
F	3.5	0	1.5	17.0
R	8.0	23.3	35.0	15.8

Note: The results have been normalized to 100% Q (quartz) + F (feldspar) + R (rock fragments). Matrix grains are those < 30 μm.

Table 2. Chemical analyses of diamictite matrix and grit using atomic absorption (MgO, Na_2O) and X-ray fluorescence (other elements). Analyses in parentheses are well outside the range of standards. Total iron is indicated as FeO. Results are compared with the composition of the average graywacke of Pettijohn (1963). L.O.I., lost on ignition (total volatiles for average graywacke). Sample localities are indicated in figure 1.*

Sample	LM 1	LM 19	LM 22	LM 31	LM 36	Average Diamictite Composition: mean	Average Diamictite Composition: s	Average Graywacke of Pettijohn (1963)
SiO_2	65.0	65.4	65.4	67.4	69.3	65.8	1.1	66.75
Al_2O_3	14.5	14.4	14.1	14.2	12.1	14.3	0.2	13.54
TiO_2	1.4	0.6	1.0	0.8	0.5	1.0	0.3	0.63
CaO	(0.5)	3.2	1.9	(0.4)	4.3	1.5	1.3	2.54
FeO*	7.3	6.4	7.0	6.1	4.2	6.7	0.5	4.98
MgO	1.7	1.4	2.3	2.2	1.2	1.9	0.4	2.15
MnO	0.07	0.12	0.15	0.12	0.23	0.12	0.03	0.12
Na_2O	1.9	2.3	2.0	2.9	5.0	2.3	0.5	2.93
K_2O	4.7	3.4	3.6	3.3	(0.6)	3.8	0.6	1.99
L.O.I.	3.0	3.3	3.7	3.5	3.3	3.4	0.3	4.46
Total	100.1	100.5	101.2	100.9	100.7	100.8		100.09
K_2O/Na_2O	2.5	1.5	1.8	1.1	0.12	1.7		0.68
	diamictite (LM 1–LM 31)				grit			

Analyses by N. Christie-Blick

Table 3. Results of clast counts in diamictite at Little Mountain (minimum clast size counted = 1 cm). Localities 1 to 4 are indicated in figure 1; locality 5 is at the southern tip of Little Mountain and locality 6 is at Landing Rocks about 1 km to the southwest.

Locality	1	2	3	4	5	6
Quartzite	5.5	14.7	15	1.5	0	tr
Carbonate	tr	0	8	0	tr	9.7
Other sedimentary	0	0	2	0	tr	4.9
Pelitic schist	0	1.0	0	1.5	tr	tr
Granite, gneiss, pegmatite	91.7	83.3	68	87.7	82.4	85.4
Vein quartz	1.8	1.0	4	3.1	2.2	0
Basic volcanic rock	0	tr	1	6.2	15.4	tr
Silicic volcanic rock	0	0	1	0	0	tr
Volcanic rock	tr	0	0	0	0	0
Unidentified	0.9	0	1	0	0	0
Total %	99.9	100.0	100	100.0	100.0	100.0
Total counted	109	102	100	65	91	103

Note: Trace (tr) implies that the clast type was observed in the outcrop but not sampled in the count.

(ed.), Glacial-marine sedimentation: Plenum Publishing, New York, p. 703–76.

Condie, K. C., 1967, Petrology of the late Precambrian tillite(?) association in northern Utah: Geological Society of America Bulletin, v. 78, p. 1317–43.

Crittenden, M. D., Jr., 1972, Willard thrust and the Cache allochthon, Utah: Geological Society of America Bulletin, v. 83, p. 2871–80.

Crittenden, M. D., Jr., Christie-Blick, N., and Link, P. K., 1983, Evidence for two pulses of glaciation during the Late Proterozoic in northern Utah and southeastern Idaho: Geological Society of America Bulletin, v. 94, p. 437–50.

Dreimanis, A., 1979, The problems of waterlain tills: In Schlüchter, C. (ed.), Moraines and Varves: Balkema, Rotterdam, p. 167–77.

Harper, G. D., and Link, P. K., 1985, Geochemistry of rift related metabasalts associated with Late Proterozoic diamictites, northern Utah and SE Idaho: Geological Society of America Abstracts with Programs, v.7, p. 223.

Harrison, J. E., and Peterman, Z. E., 1980, North American Commission on Stratigraphic Nomenclature Note 52—a preliminary proposal for a chronometric time scale for the Precambrian of the United States and Mexico: Geological Society of America Bulletin, v. 91, pt. 1, p. 377–80.

Harrison, J. E., and Peterman, Z. E., 1982, North American Commission on Stratigraphic Nomenclature Report 9—adoption of geochronometric units for divisions of Precambrian time: American Association of Petroleum Geologists Bulletin, v. 66, p. 801–4.

Ojakangas, R. W., and Matsch, C. L., 1980, Upper Precambrian (Eocambrian) Mineral Fork Tillite of Utah: a continental glacial and glaciomarine sequence: Geological Society of America Bulletin, v. 91, pt. 1, p. 495–501.

Pettijohn, F. J., 1963, Chemical composition of sandstones—excluding carbonate and volcanic sands: U.S. Geological Survey Professional Paper 440-S, 21p.

Pettijohn, F. J., Potter, P. E., and Siever, R., 1973, Sand and sandstone: Springer-Verlag, New York, 618p.

Sorensen, M. L., and Crittenden, M. D., Jr., 1976, Preliminary geologic map of the Mantua Quadrangle and part of the Willard Quadrangle, Box Elder, Weber and Cache Counties, Utah: U.S. Geological Survey, Miscellaneous Field Studies Map MF-720, scale 1:24,000.

Varney, P. J., 1976, Depositional environment of the Mineral Fork Formation (Precambrian), Wasatch Mountains, Utah: In Hill, J. G. (ed.), Geology of the Cordilleran hinge-line: Rocky Mountain Association of Geologists, Symposium, p. 91–102.

Williams, H., Turner, F. J., and Gilbert, C. M., 1982, Petrography (2d ed.): W. H. Freeman and Co., San Francisco, 626p.

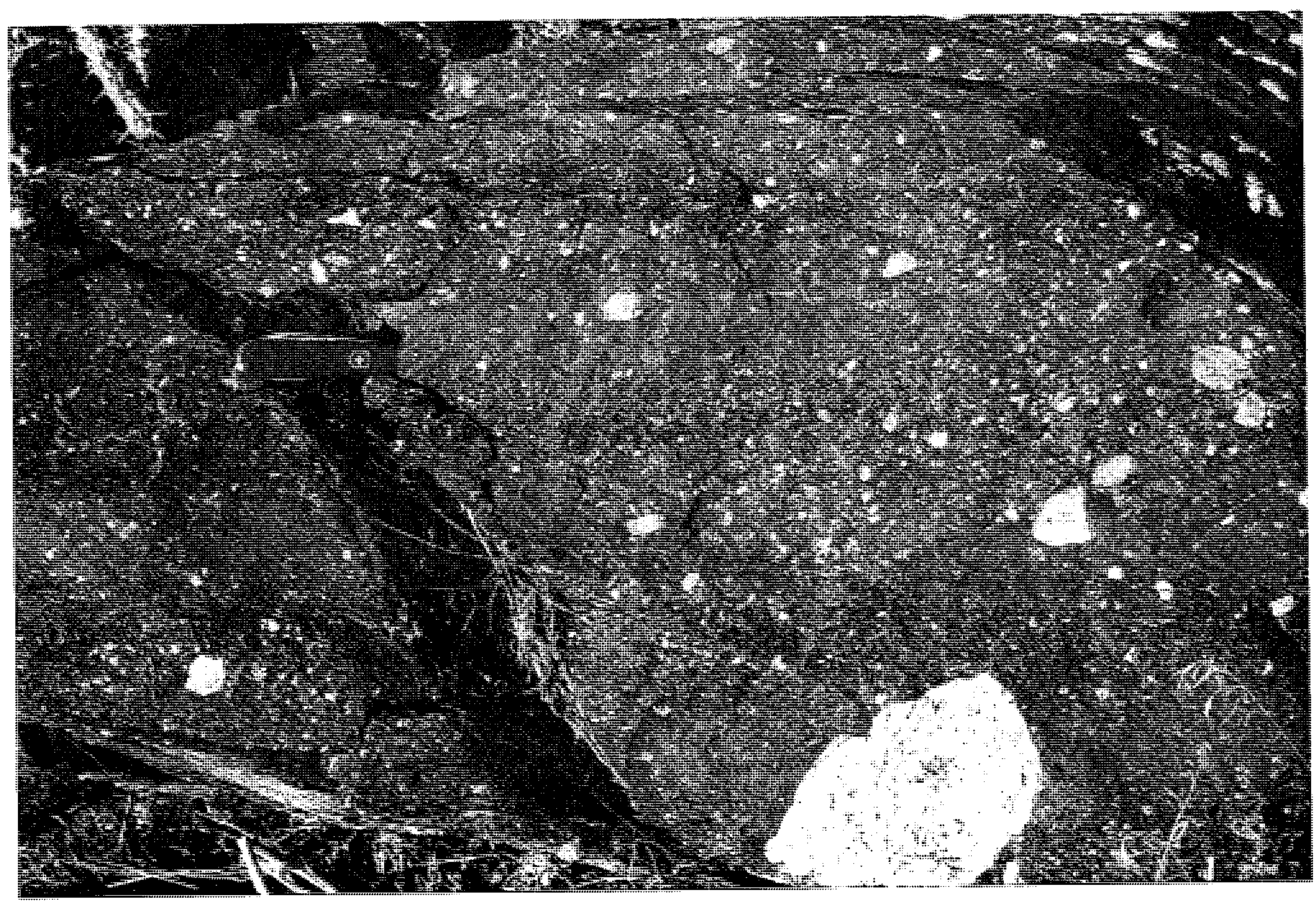

FIGURE 6.—*Feldspathic, gritty pod in diamictite, probably a product of winnowing.*

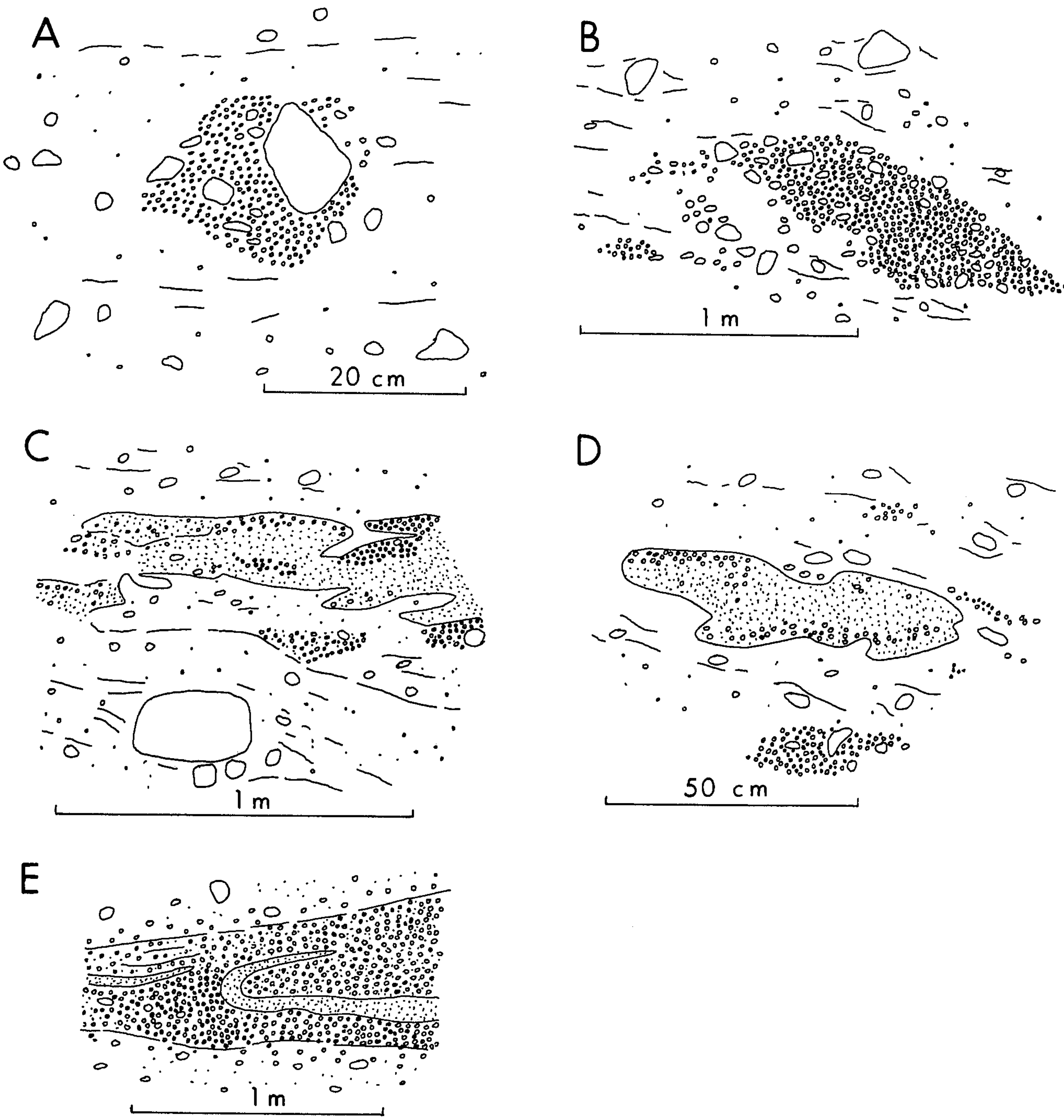

FIGURE 7.—*Sketches of clots of rafted(?) detritus in diamictite (A and B) and lenses indicating current activity (C, D, and E). A, pebbly sandstone; B, grit; C, sandstone; D, grit; E, deformed sandstone and grit.*