HETEROGENEOUS SHALLOW-SHELF CARBONATE BUILDUPS IN THE PARADOX BASIN, UTAH AND COLORADO: TARGETS FOR INCREASED OIL PRODUCTION AND RESERVES USING HORIZONTAL DRILLING TECHNIQUES

(Contract No. DE-2600BC15128)

DELIVERABLE 2.1.1 POROSITY/PERMEABILITY CROSS-PLOTS: CHEROKEE AND BUG FIELDS, SAN JUAN COUNTY, UTAH, AND LITTLE UTE AND SLEEPING UTE FIELDS, MONTEZUMA COUNTY, COLORADO

Submitted by

Utah Geological Survey
Salt Lake City, Utah 84114
December 2003

Contracting Officer's Representative

Gary D. Walker, Contract Manager
U.S. Department of Energy
National Petroleum Technology Office
1 West 3rd Street
Tulsa, OK 74103-3532

DISCLAIMER

HETEROGENEOUS SHALLOW-SHELF CARBONATE BUILDUPS IN THE PARADOX BASIN, UTAH AND COLORADO: TARGETS FOR INCREASED OIL PRODUCTION AND RESERVES USING HORIZONTAL DRILLING TECHNIQUES

(Contract No. DE-2600BC15128)

DELIVERABLE 2.1.1 POROSITY/PERMEABILITY CROSS-PLOTS: CHEROKEE AND BUG FIELDS, SAN JUAN COUNTY, UTAH, AND LITTLE UTE AND SLEEPING UTE FIELDS, MONTEZUMA COUNTY, COLORADO

Submitted by

Utah Geological Survey
Salt Lake City, Utah 84114
December 2003

by

Thomas C. Chidsey, Jr., Principal Investigator/Program Manager, Utah Geological Survey,
David E. Eby, Eby Petrography & Consulting, Inc.
and
Laura L. Wray, Colorado Geological Survey

CONTENTS

FIGURES

TABLES

INTRODUCTION

Over 400 million barrels (64 million m^3) of oil have been produced from the shallow-shelf carbonate reservoirs in the Pennsylvanian (Desmoinesian) Paradox Formation in the Paradox Basin, Utah and Colorado. With the exception of the giant Greater Aneth field, the other 100 plus oil fields in the basin typically contain 2 to 10 million barrels (0.3-1.6 million m^3) of original oil in place. Most of these fields are characterized by high initial production rates followed by a very short productive life (primary), and hence premature abandonment. Only 15 to 25 percent of the original oil in place is recoverable during primary production from conventional vertical wells.

An extensive and successful horizontal drilling program has been conducted in the giant Greater Aneth field. However, to date, only two horizontal wells have been drilled in small Ismay and Desert Creek fields. The results from these wells were disappointing due to poor understanding of the carbonate facies and diagenetic fabrics that create reservoir heterogeneity. These small fields, and similar fields in the basin, are at high risk of premature abandonment. At least 200 million barrels (31.8 million m^3) of oil will be left behind in these small fields because current development practices leave compartments of the heterogeneous reservoirs undrained. Through proper geological evaluation of the reservoirs, production may be increased by 20 to 50 percent through the drilling of low-cost single or multilateral horizontal legs from existing vertical development wells. In addition, horizontal drilling from existing wells minimizes surface disturbances and costs for field development, particularly in the environmentally sensitive areas of southeastern Utah and southwestern Colorado.

GEOLOGIC SETTING

The Paradox Basin is located mainly in southeastern Utah and southwestern Colorado with a small portion in northeastern Arizona and the northwestern most corner of New Mexico (figure 1). The Paradox Basin is an elongate, northwest-southeast trending evaporitic basin that predominately developed during the Pennsylvanian (Desmoinesian), about 330 to 310 million years ago (Ma). During the Pennsylvanian, a pattern of basins and fault-bounded uplifts developed from Utah to Oklahoma as a result of the collision of South America, Africa, and southeastern North America (Kluth and Coney, 1981; Kluth, 1986), or from a smaller scale collision of a microcontinent with south-central North America (Harry and Mickus, 1998). One result of this tectonic event was the uplift of the Ancestral Rockies in the western United States. The Uncompahgre Highlands in eastern Utah and western Colorado initially formed as the westernmost range of the Ancestral Rockies during this ancient mountain-building period. The Uncompahgre Highlands (uplift) is bounded along the southwestern flank by a large basement-involved, high-angle reverse fault identified from geophysical seismic surveys and exploration drilling. As the highlands rose, an accompanying depression, or foreland basin, formed to the southwest — the Paradox Basin. Rapid subsidence, particularly during the Pennsylvanian and then continuing into the Permian, accommodated large volumes of evaporitic and marine sediments that intertongue with non-marine arkosic material shed from the highland area to the northeast (Hintze, 1993). The Paradox Basin is surrounded by other uplifts and basins that formed during the Late Cretaceous-early Tertiary Laramide orogeny (figure 1).

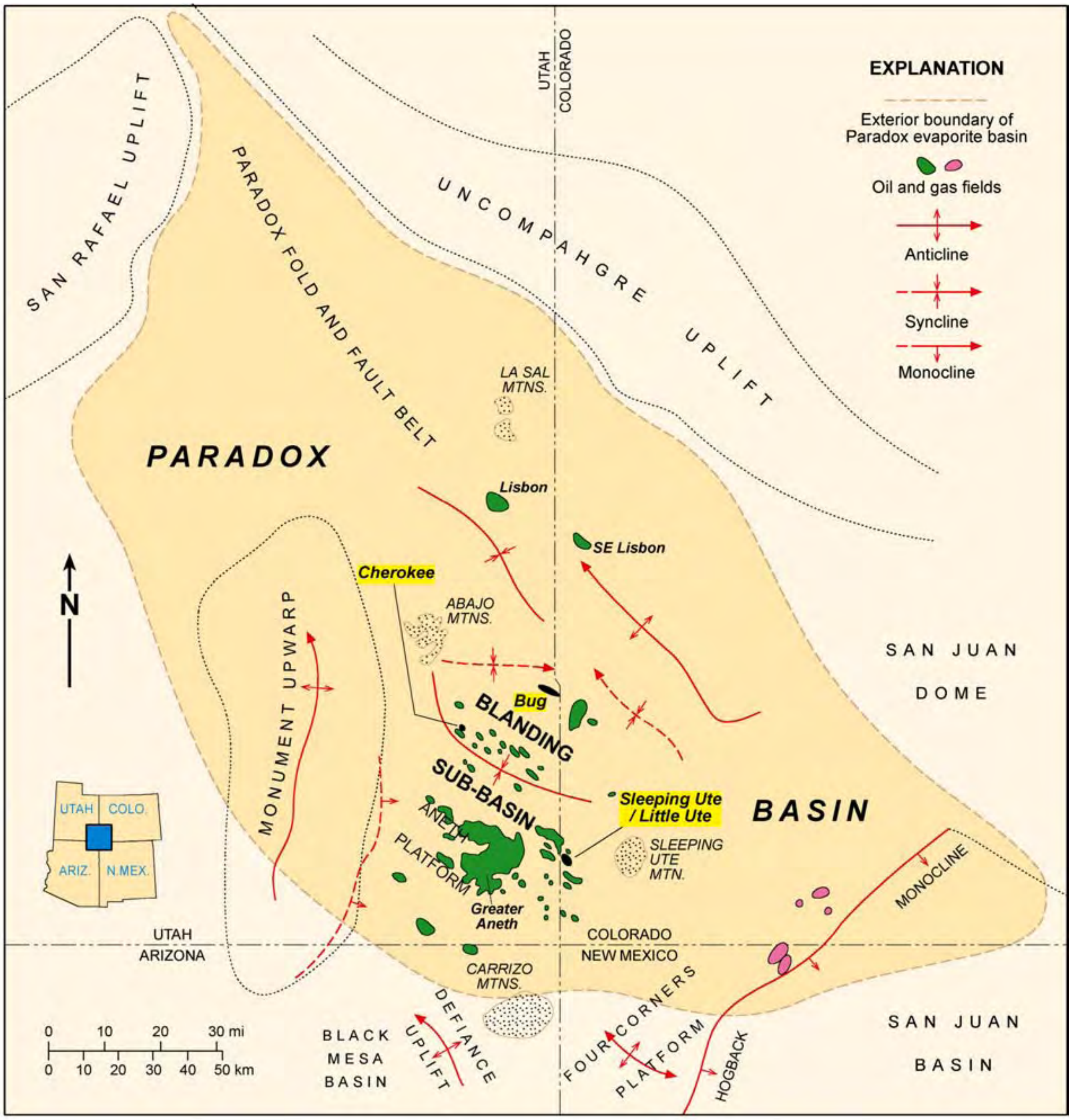


Figure 1. Location map of the Paradox Basin, Utah, Colorado, Arizona, and New Mexico showing producing oil and gas fields, the Paradox fold and fault belt, and Blanding sub-basin as well as surrounding Laramide basins and uplifts (modified from Harr, 1996).

The Paradox Basin can generally be divided into two areas: the Paradox fold and fault belt in the north, and the Blanding sub-basin in the south-southwest (figure 1). Most oil production comes from the Blanding sub-basin. The source of the oil is several black, organic-rich shales within the Paradox Formation (Hite and others, 1984; Nuccio and Condon, 1996). The relatively undeformed Blanding sub-basin developed on a shallow-marine shelf which locally contained algal-mound and other carbonate buildups in a subtropical climate.

The two main producing zones of the Paradox Formation are informally named the Ismay and the Desert Creek (figure 2). The Ismay zone is dominantly limestone comprising equant buildups of phylloid-algal material with locally variable small-scale subfacies (figure 3A) and capped by anhydrite. The Ismay produces oil from fields in the southern Blanding sub-basin (figure 4). The Desert Creek zone is dominantly dolomite comprising regional nearshore shoreline trends with highly aligned, linear facies tracts (figure 3B). The Desert Creek produces oil in fields in the central Blanding sub-basin (figure 4). Both the Ismay and Desert Creek buildups generally trend northwest-southeast. Various facies changes and extensive diagenesis have created complex reservoir heterogeneity within these two diverse zones.

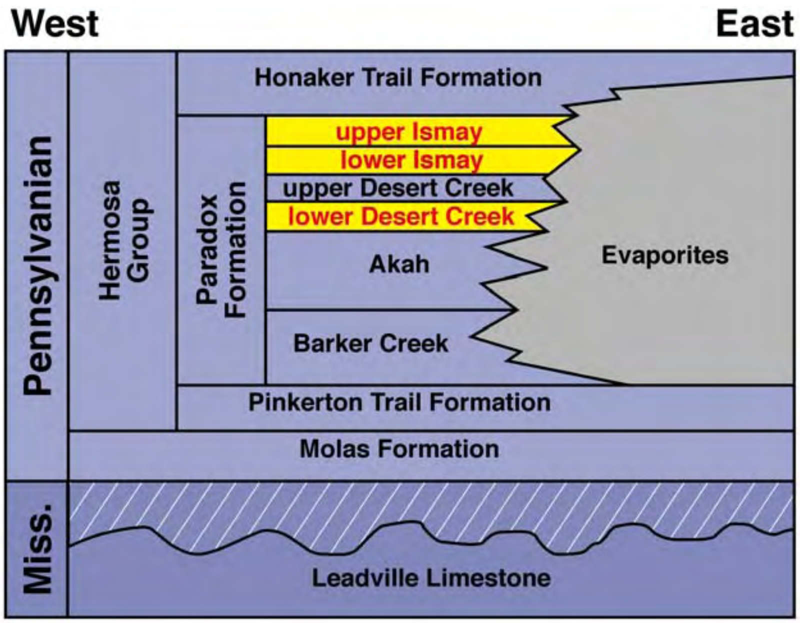


***Figure 2.** Pennsylvanian stratigraphy of the southern Paradox Basin including informal zones of the Paradox Formation; the Ismay and Desert Creek zones productive in the case-study fields described in this report are highlighted.*

CASE-STUDY FIELDS

Two Utah fields were selected for local-scale evaluation and geological characterization: Cherokee in the Ismay trend and Bug in the Desert Creek trend (figure 4). Two Colorado fields are also selected for evaluation: Little Ute and Sleeping Ute in the Ismay trend (figure 4). This evaluation included data collection and plots of core plug porosity versus permeability of these fields as summarized in this report.

This geological characterization focused on reservoir heterogeneity, quality, and lateral continuity, as well as possible compartmentalization within the fields. From these evaluations, untested or under-produced compartments can be identified as targets for horizontal drilling. The models resulting from the geological and reservoir characterization of these fields can be applied to similar fields in the basin (and other basins as well) where data might be limited.

Cherokee Field

Cherokee field (figure 4) is a phylloid-algal buildup capped by anhydrite that produces from porous algal limestone and dolomite in the upper Ismay zone. The net reservoir thickness is 27 feet (8.2 m), which extends over a 320-acre (130 ha) area. Porosity averages 12 percent with 8 millidarcies (md) of permeability in vuggy and intercrystalline pore systems. Water saturation is 38.1 percent (Crawley-Stewart and Riley, 1993).

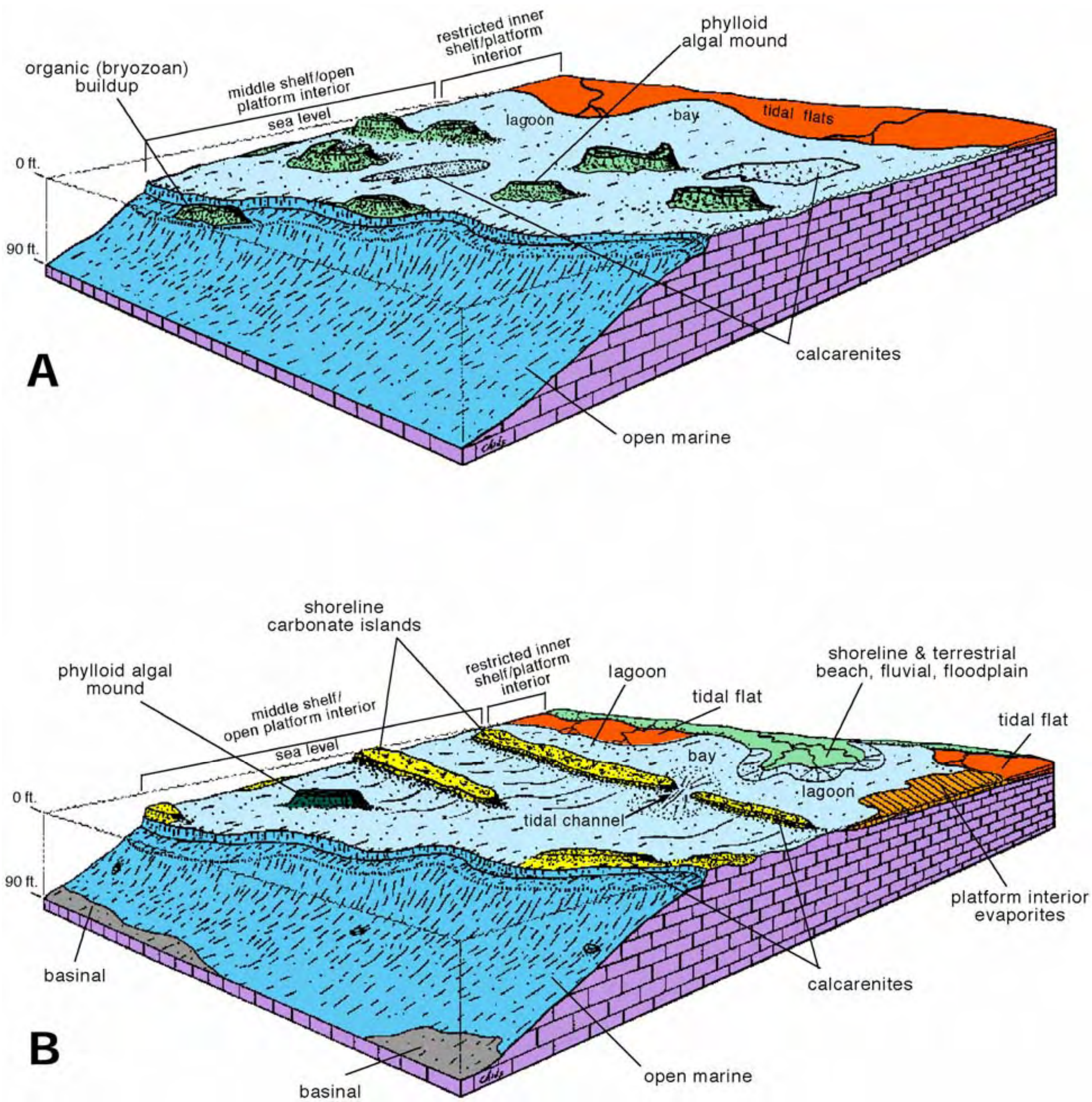


Figure 3. Block diagrams displaying major depositional facies, as determined from core, for the Ismay (A) and Desert Creek (B) zones, Pennsylvanian Paradox Formation, Utah and Colorado.

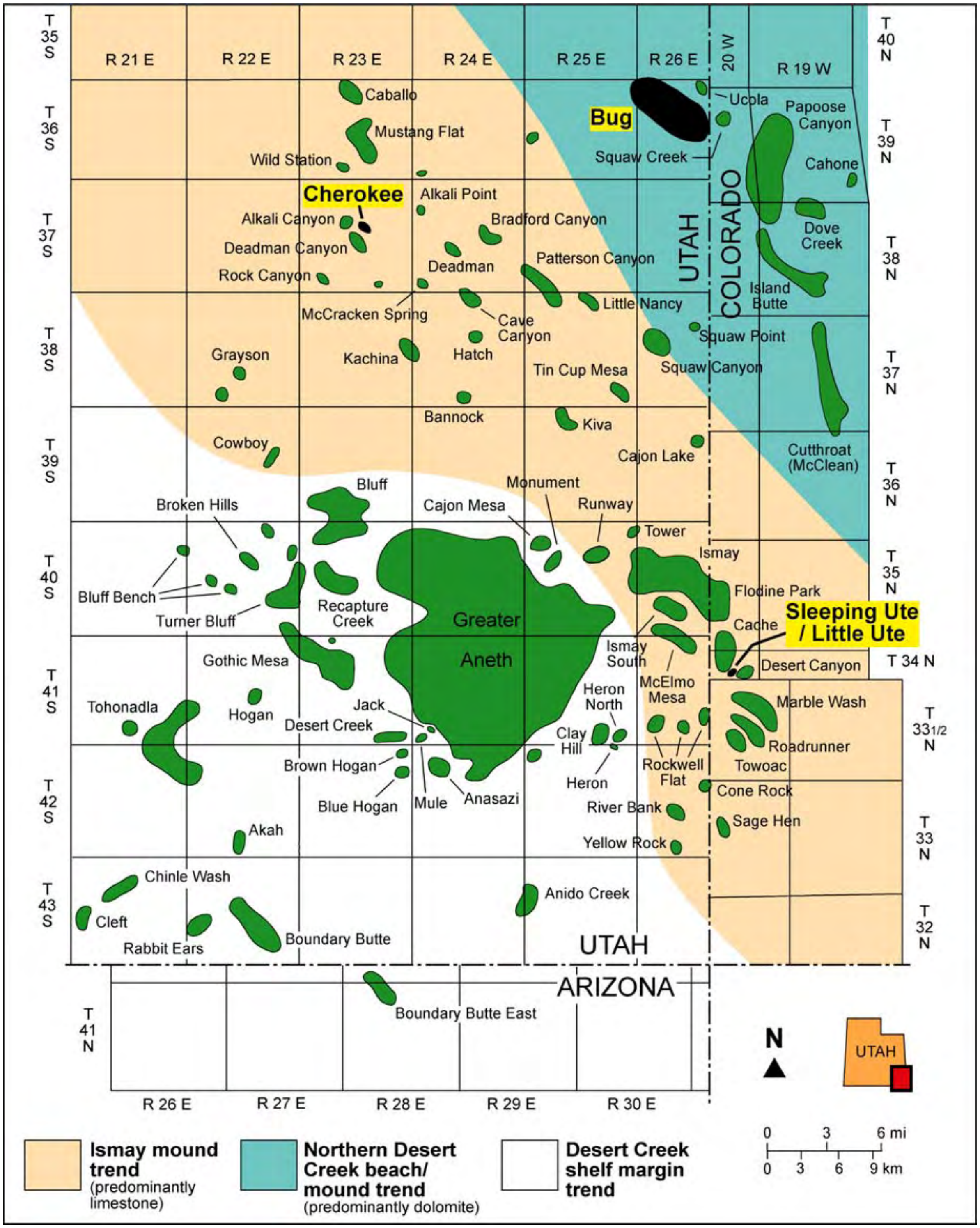


Figure 4. Map showing the project study area and fields (case-study fields in black) within the Ismay and Desert Creek producing trends in the Blanding sub-basin, Utah and Colorado.

Cherokee field was discovered in 1987 with the completion of the Meridian Oil Company Cherokee Federal 11-14, NE1/4NW1/4 section 14, T. 37 S., R. 23 E., Salt Lake Base Line and Meridian (SLBL&M); initial potential flow (IPF) was 53 barrels of oil per day (BOPD) (8.4 m^3), 990 thousand cubic feet of gas per day (MCFGPD) (28 MCMPD), and 26 barrels of water (4.1 m^3). There are currently four producing (or shut-in) wells and two dry holes in the field. The well spacing is 80 acres (32 ha). The present field reservoir pressure is estimated at 150 pounds per square inch (psi) (1,034 Kpa). Cumulative production as of June 1, 2003, was 182,071 barrels of oil (28,949 m^3), 3.65 billion cubic feet of gas (BCFG) (0.1 BCMG), and 3,358 barrels of water (534 m^3) (Utah Division of Oil, Gas and Mining, 2003). The original estimated primary recovery is 172,000 barrels of oil (27,348 m^3) and 3.28 BCFG (0.09 BCMG) (Crawley-Stewart and Riley, 1993). The fact that both these estimates have been surpassed suggests significant additional reserves could remain.

Bug Field

Bug field (figure 4) is an elongate, northwest-trending carbonate buildup in the lower Desert Creek zone. The producing units vary from porous dolomite ized bafflestone to packstone and wackestone. The trapping mechanism is an updip porosity pinchout. The net reservoir thickness is 15 feet (4.6 m) over a 2,600-acre (1,052 ha) area. Porosity averages 11 percent in moldic, vuggy, and intercrystalline networks. Permeability averages 25 to 30 md, but ranges from less than 1 to 500 md. Water saturation is 32 percent (Martin, 1983; Oline, 1996).

Bug field was discovered in 1980 with the completion of the Wexpro Bug No. 1, NE1/SE1/4 section 12, T. 36 S., R. 25 E., SLBL&M, for an IPF of 608 BOPD (96.7 m^3), 1,128 MCFGPD (32 MCMPD), and 180 barrels of water (28.6 m^3). There are currently eight producing (or shut-in) wells, five abandoned producers, and two dry holes in the field. The well spacing is 160 acres (65 ha). The present reservoir field pressure is 3,550 psi (24,477 Kpa). Cumulative production as of June 1, 2003, was 1,622,2020 barrels of oil (257,901 m^3), 4.47 BCFG (0.13 BCMG), and 3,181,448 barrels of water (505,850 m^3) (Utah Division of Oil, Gas and Mining, 2003). Estimated primary recovery is 1,600,000 bbls (254,400 m^3) of oil and 4 BCFG (0.1 BCMG) (Oline, 1996). Again, since the original reserve estimates have been surpassed and the field is still producing, significant additional reserves likely remain.

Little Ute and Sleeping Ute Fields

Little Ute and Sleeping Ute fields are located in Montezuma County, Colorado (sections 3, 10, and 11, T. 34 N., R. 20 W. (figure 4). The producing reservoirs consist of phylloid-algal buildups in the Ismay zone flanked by bryozoan mounds and mound flank debris. These porous mounds, capped by impermeable anhydritic dolomite, produce primarily from porous phylloid-algal limestones, some of which have been dolomitized. The net reservoir thickness is 30 feet (9.1 m), which extends over approximately 640 acres (260 ha). Porosity ranges from 4 to 20 percent with 1 to 98 millidarcies (md) of permeability in vuggy and intercrystalline pore systems.

The first well drilled in the Little Ute/ Sleeping Ute study area was a dry hole, completed in 1959. The Calvert Drilling Company Desert Canyon No. 1 was drilled in the SW/4 of section 10, T. 34 N., R. 20 W., to a total depth of 5,938 feet (1,810 m) to the Gothic shale as a test of the Ismay and Desert Creek zones of the Paradox Formation. The well was plugged and abandoned on September 29, 1959, after a drill-stem test and four cores were taken in the Ismay and Desert

Creek. The results of the drill-stem test, taken over the interval of 5,697 to 5,840 feet (1,736-1,780 m), were discouraging in that there was a very weak blow of air to the surface that died in 5 minutes and only 55 feet (17 m) of drilling mud was recovered. Somewhat more encouraging were the cores taken from 5,675 to 5,739 feet (1,730-1,749 m), 5,729 to 5,782 feet (1,746-1,762 m), 5,782 to 5,820 feet (1,762-1,774 m), and 5,880 to 5,938 feet (1,792-1,819 m). Over that entire interval, there were favorable reports of petroliferous odor, visible vuggy and intercrystalline porosity, and bleeding oil.

There are currently three producing wells and three dry holes in the Little Ute and Sleeping Ute study area proper. Well spacing is 80 acres (32 ha). The net reservoir thickness is 20 feet (6 m) over a 240-acre (97 ha) area. Porosity averages 15 percent and permeability is 0.01 to 2 md. Water saturation is 50 percent (Ghazal, 1978). Cumulative production from these three wells, plus the Desert Canyon No. 3 well that defined the Desert Canyon field, exceeds 325,000 barrels (51,675 m^3) of oil and 750 million cubic feet (21 million m^3) of gas.

Porosity and Permeability Cross-plots

Porosity and permeability data (Appendix A) from core plugs were obtained from the two Cherokee, five of the eight Bug, one Little Ute, and one Sleeping Ute wells that were cored (table 1 and Excel ® spread sheet on diskette[1]). Cross-plots of these data are used to: (1) determine the most effective pore systems for oil storage versus drainage, (2) identify reservoir heterogeneity, (3) predict potential untested compartments, (4) infer porosity and permeability trends where core-plug data are not available, and (5) match diagenetic processes, pore types, mineralogy, and other attributes to porosity and permeability distribution.

Table 1. List of well conventional slabbed core examined and described from project fields in the Paradox Basin of Utah and Colorado.

Well	Location	API No.	Cored Interval (ft)	Field	Stratigraphic Zone	Repository*
May-Bug 2	7-36S-26E, UT	43-037-30543	6290-6333	Bug	Desert Creek	UGS
Bug 3	7-36S-26E, UT	43-037-30544	6316-6358	Bug	Desert Creek	UGS
Bug 4	16-36S-26E, UT	43-037-30542	6278-6322	Bug	Desert Creek	UGS
Bug 7A	7-36S-26E, UT	43-037-30730	6345-6400	Bug	Desert Creek	UGS
Bug 8	8-36S-26E, UT	43-037-30589	5737-5796.1	Bug	Desert Creek	UGS
Bug 10	22-36S-26E, UT	43-037-30591	6300-6346.5	Bug	Desert Creek	UGS
Bug 13	17-36S-26E, UT	43-037-30610	5913-5951.3	Bug	Desert Creek	UGS
Bug 16	17-36S-26E, UT	43-037-30607	6278-6333	Bug	Desert Creek	UGS
Cherokee 22-14	14-37S-23E, UT	43-037-31367	5768-5880	Cherokee	Ismay	UGS
Cherokee 33-14	14-37S-23E, UT	43-037-31316	5770-5799	Cherokee	Ismay	UGS
Little Ute 1	11-34N-20W, CO	05-083-06553	5836-5955.3	Little Ute	Ismay	TOS
Sleeping Ute 1	3-34N-20W, CO	05-083-06540	5533-5653	Sleeping Ute	Ismay	TOS

* UGS = Utah Geological Survey, Salt Lake City, Utah; TOS = Triple O Slabbing, Denver, Colorado

[1] To view data right click on chart and navigate to source data, series tab. Proceed by viewing x and y values. Before switching values highlight series in series window then back to x or y value.

Cherokee and Bug Fields

Fifty-eight porosity and permeability cross-plots (see figures B-1 through B-48 in Appendix B) were constructed using the available data for Cherokee and Bug fields. Data classes within the plots included perforated limestone intervals, perforated dolomite intervals, total perforated intervals, reservoir facies, carbonate fabric, pore type, and core with a 6 percent porosity and 2 md economic cutoff.

In general, analysis of the Cherokee and Bug plots shows that those zones that have been dolomitized have better reservoir potential than those that remain limestone (figure 5). The dominant pore type (microporosity/channel, moldic, intercrystalline, interparticle, and shelter/vuggy) was assigned to each porosity/permeability data point that was cross-plotted. The graph for the Cherokee No. 22-14 well from Cherokee field indicates that those samples with microporosity have the best reservoir potential, while those with intercrystalline porosity have the poorest reservoir potential (figure 6). The graph for the May-Bug No. 2 well from Bug field indicates that those samples with intercrystalline porosity in micro-box-work dolomite have the best reservoir potential (figure 7). The dominant facies type (mound/breccia, calcarenites, open marine, and middle/inner shelf) was also assigned to each porosity/permeability data point that was cross-plotted. No specific trend between facies type and porosity/permeability was identified. However, in Cherokee field, better reservoir qualities are generally found in calcarenite facies than in other facies, and in Bug field (figure 8), the better reservoir qualities are found in mound/breccia facies. Thus, our conclusion is that the reservoir quality of the rocks in Cherokee and Bug fields is more dependent on pore types and diagenesis than on facies type.

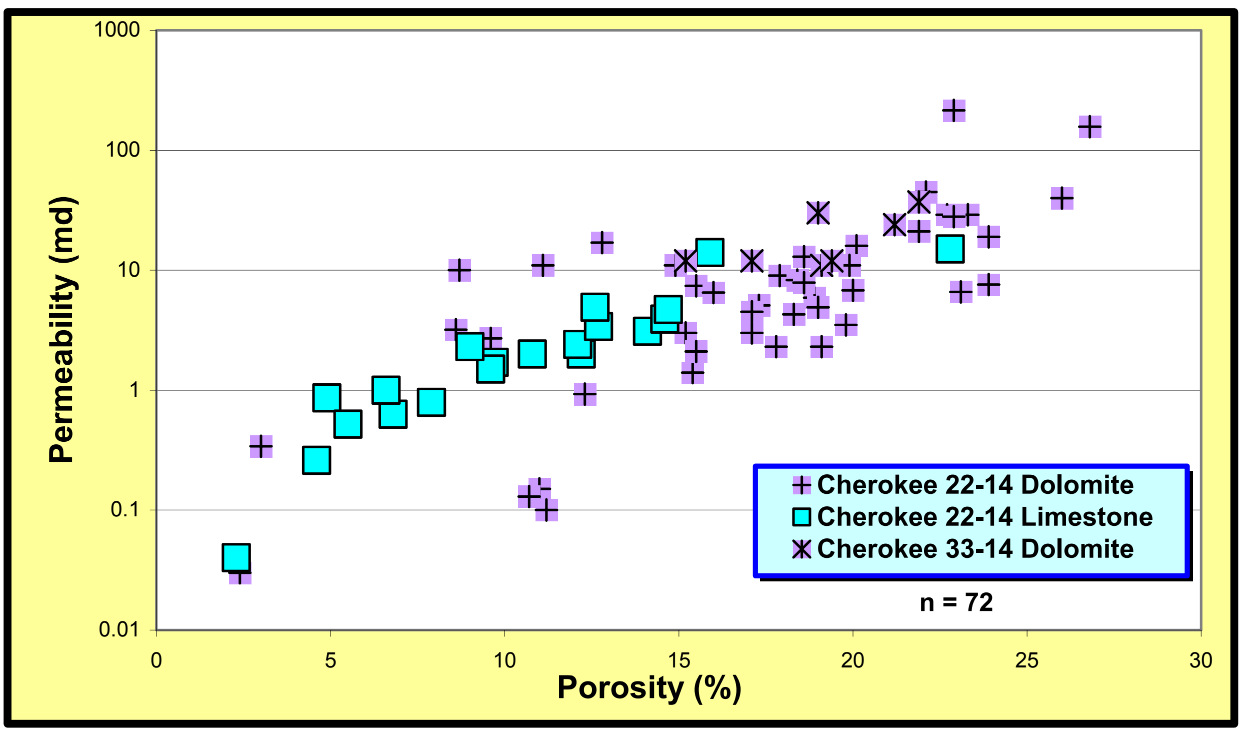


Figure 5. Cherokee field permeability versus porosity cross-plot of perforated limestone and dolomite intervals.

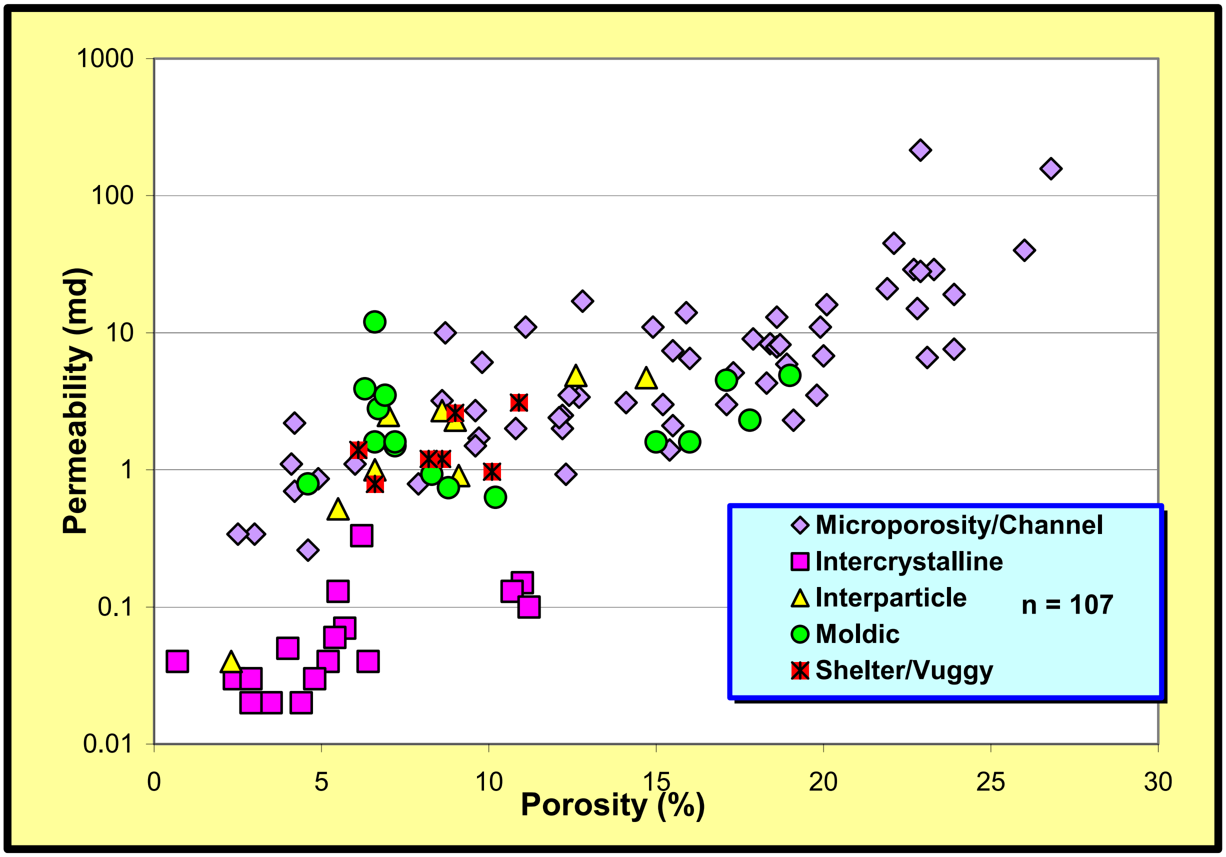


Figure 6. Cherokee No. 22-14 well permeability versus porosity cross-plot by pore types and diagenesis.

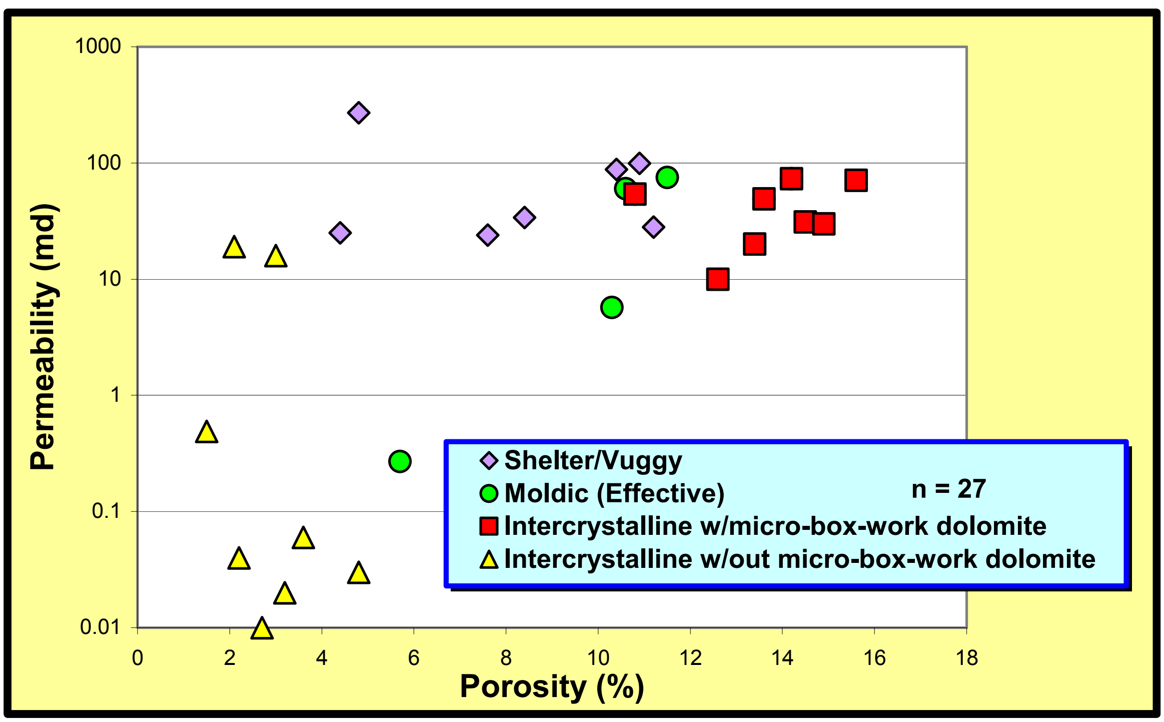


Figure 7. May-Bug No. 2 well permeability versus porosity cross-plot by pore types and diagenesis.

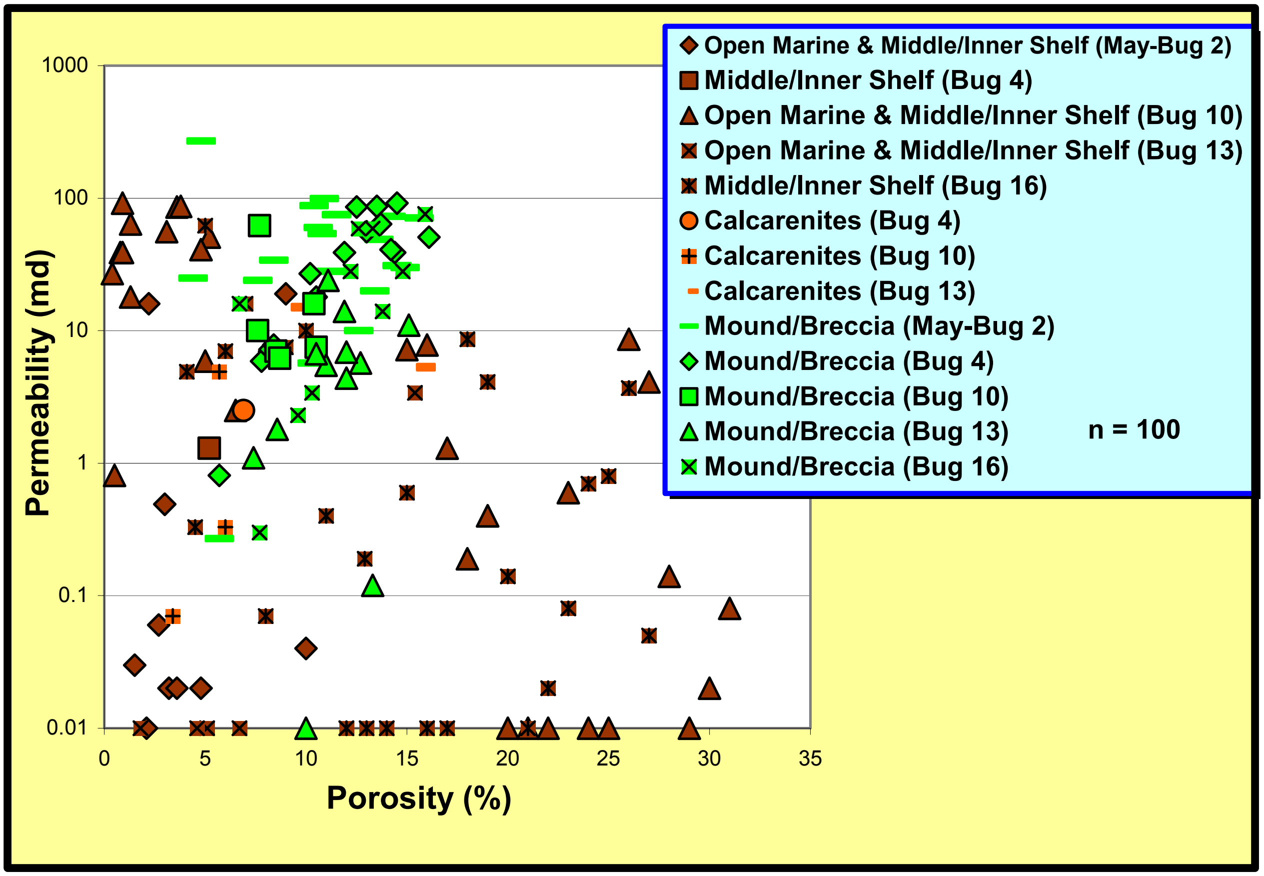


Figure 8. Bug field permeability versus porosity cross-plot by facies.

Little Ute and Sleeping Ute Fields

Cross-plots of porosity versus permeability for the various pore types for the two cored wells in Little Ute and Sleeping Ute fields, seen in figures 9 and 10, show that intercrystalline and moldic pore types have the highest porosity and permeability of any of the other pore types. They also have a wide range of values with some samples being among the lowest for porosity and permeability. Again, the rough economic cutoff for permeability was found to be 2 md. Accordingly, the productive Little Ute No. 1 well has a number of cored intervals that exceed 2 md, whereas the Sleeping Ute No. 1, a dry hole, has many fewer intervals greater than 2 md.

Cross-plots of porosity versus permeability for the various facies are seen in figures 11 and 12. Using the 2 md economic cutoff, the productive Little Ute No. 1 well (figure 11) contains numerous phylloid-algal mound reservoir intervals. By comparison, the non-productive Sleeping Ute No. 1 well contains no phylloid-algal mound facies. Only a few intervals in the Sleeping Ute No. 1 core (figure 12) exceed the 2 md cutoff.

Cross-plots of the mineralogy are shown for the two-cored wells in figures 13 and 14. Once again, the intervals that exceed 2 md are greater in number in the productive Little Ute No. 1 well (figure 13) than in the non-productive Sleeping Ute No. 1 well (figure 14). No single mineralogy seems to dominate the reservoir intervals in the Little Ute No. 1 core. In contrast, the non-productive Sleeping Ute No. 1 core has very few intervals with permeabilities greater than 2 md. The few samples that do fall into the higher permeability range are almost exclusively anhydritic dolomites.

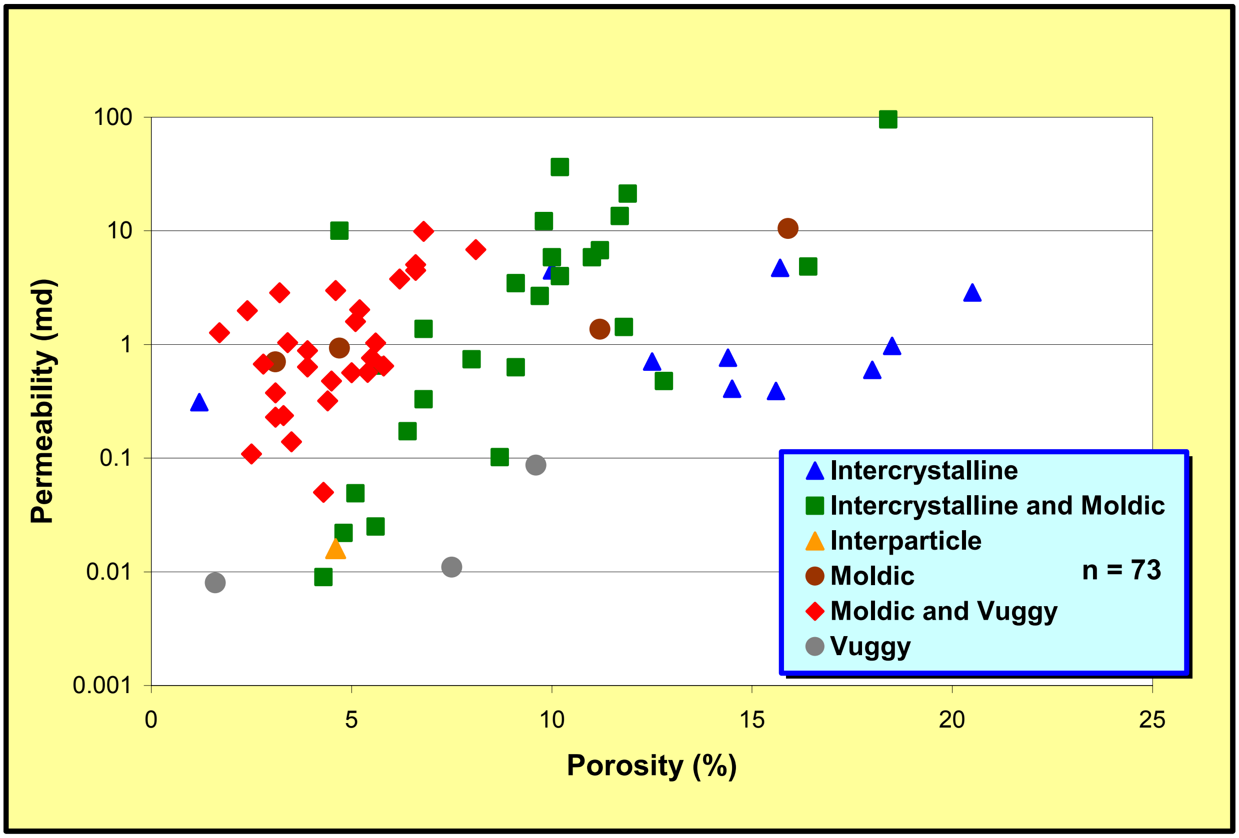


Figure 9. Little Ute No. 1 well permeability versus porosity cross plot by pore types.

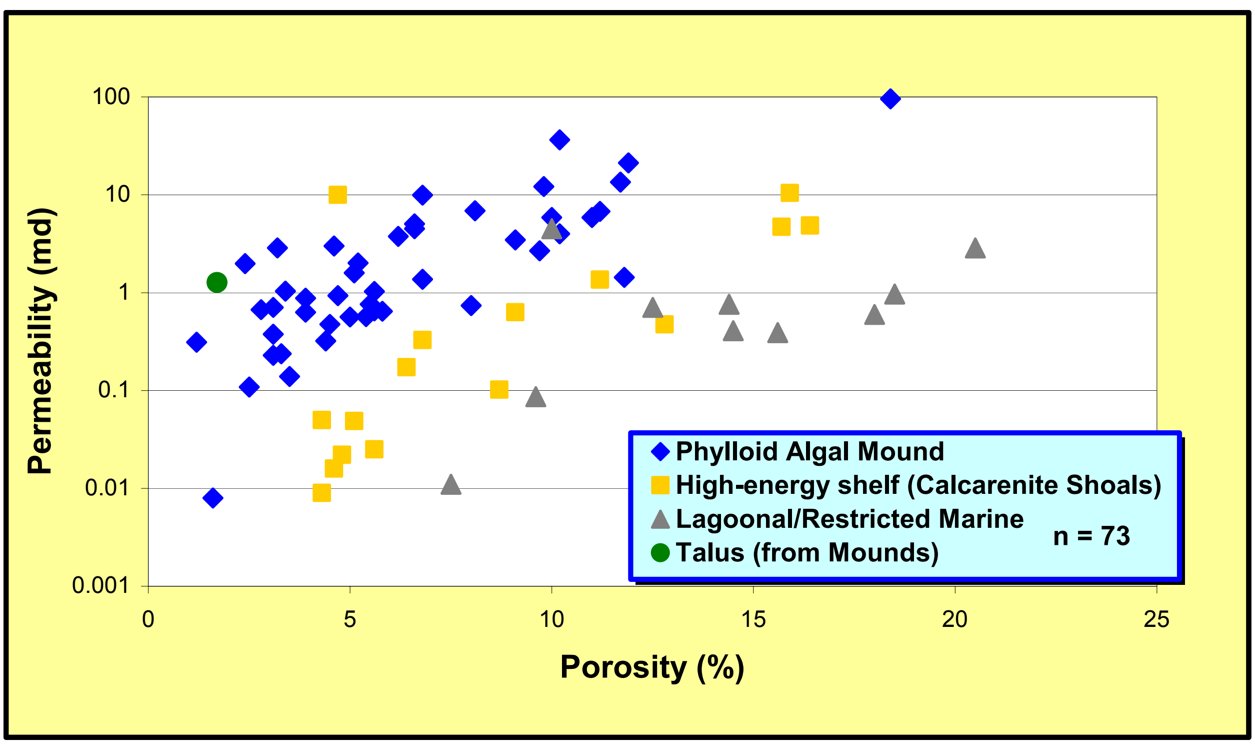


Figure 10. Sleeping Ute No. 1 well permeability versus porosity cross plot by pore types.

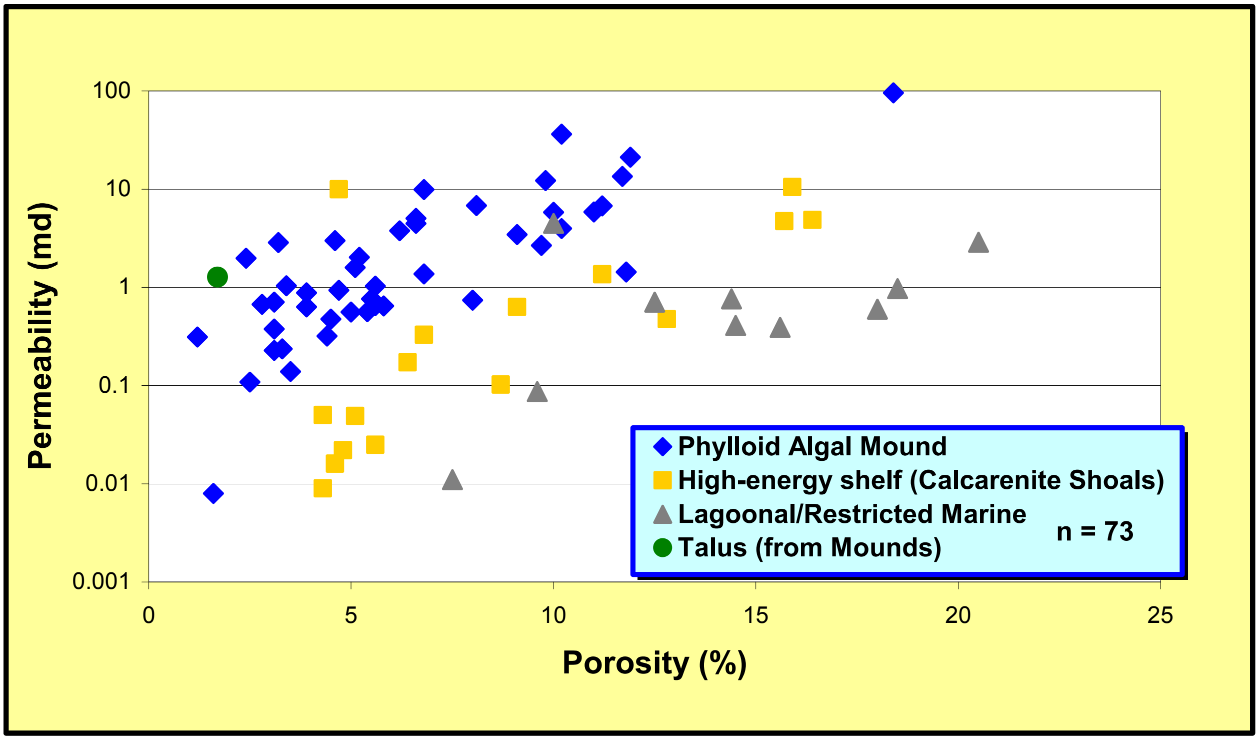


Figure 11. Little Ute No. 1 well permeability versus porosity cross plot by facies.

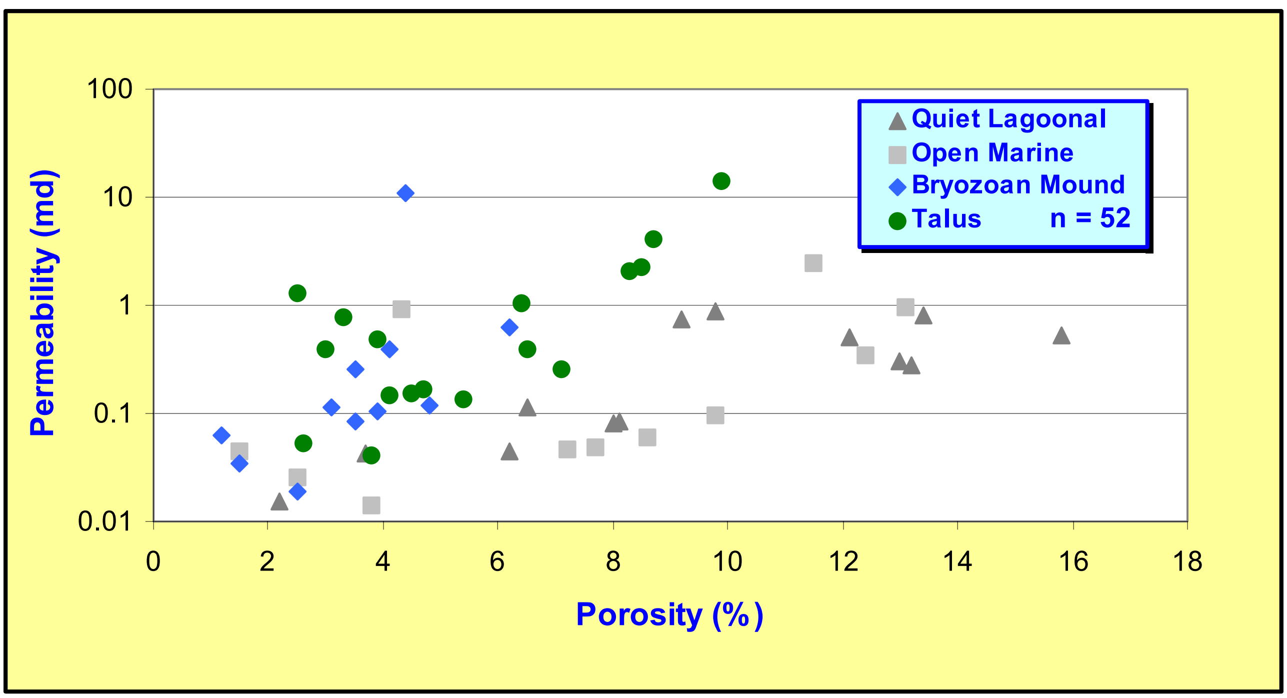


Figure 12. Sleeping Ute No. 1 well permeability versus porosity cross plot by facies.

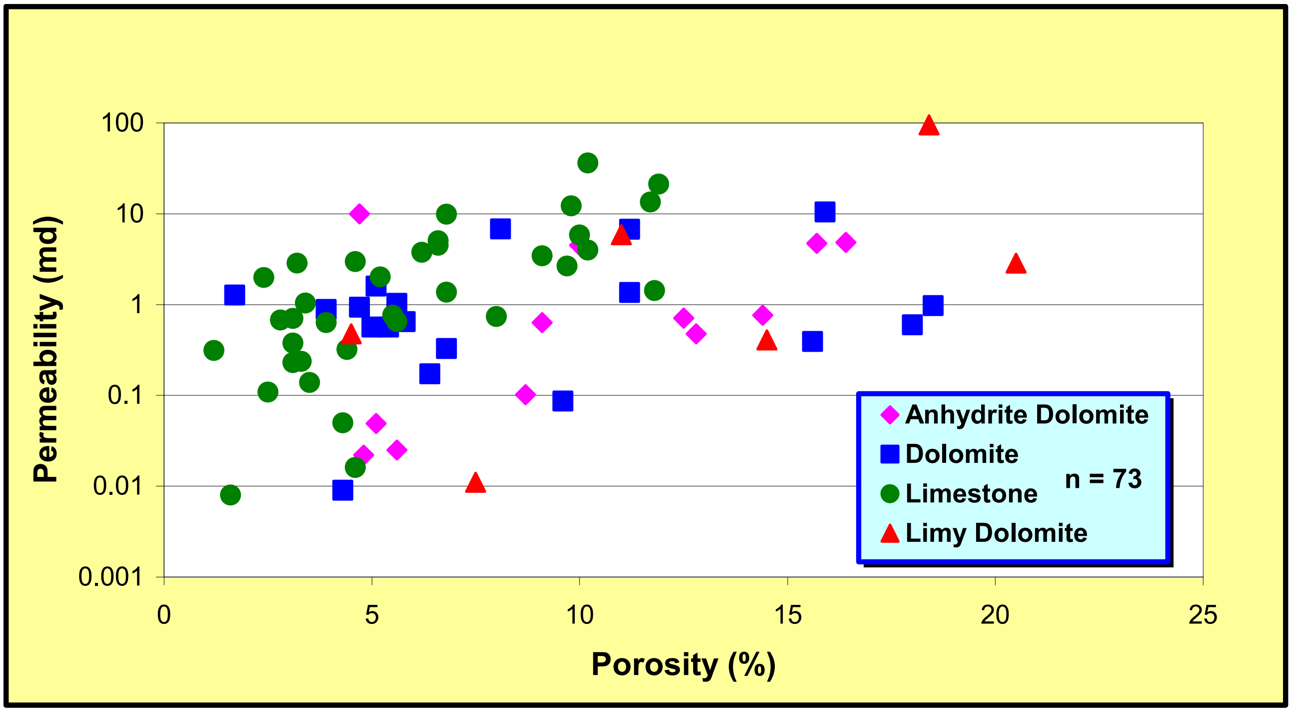


Figure 13. Little Ute No. 1 well permeability versus porosity cross plot by mineralogy.

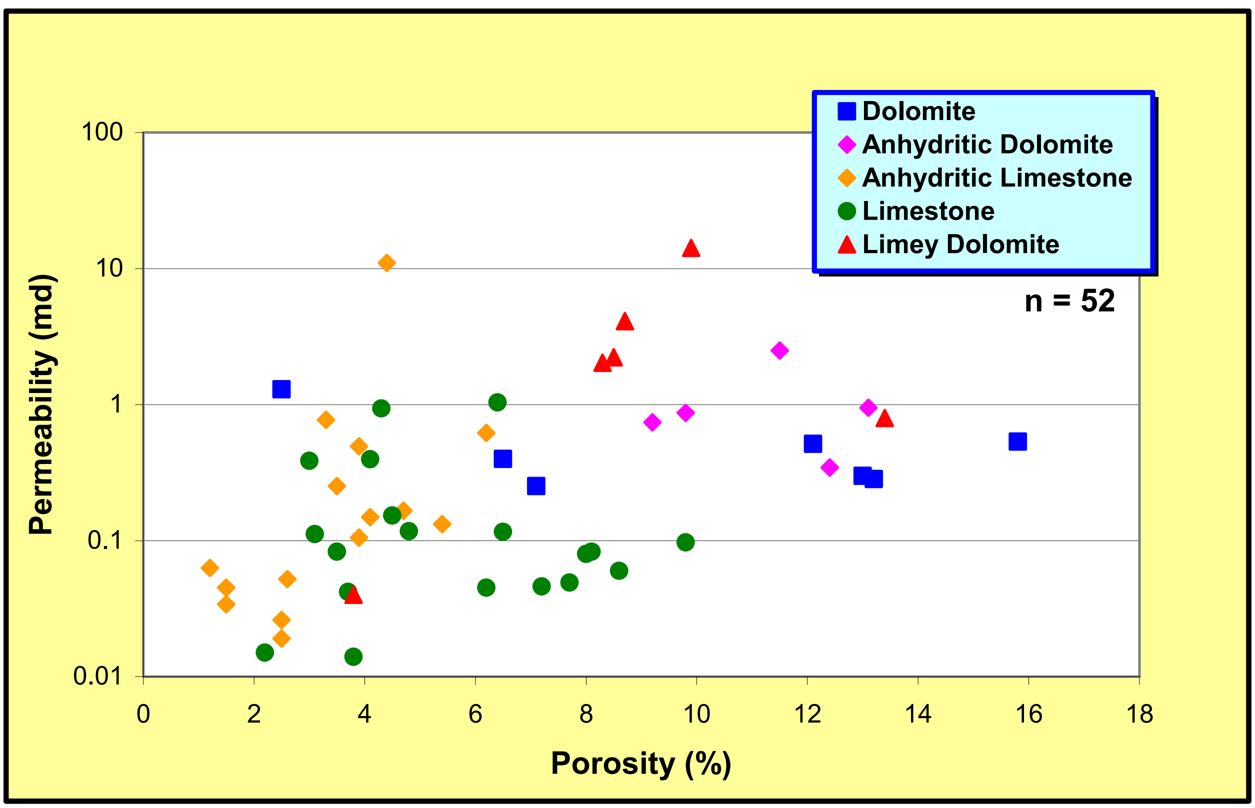


Figure 14. Sleeping Ute No. 1 well permeability versus porosity cross plot by mineralogy.

ACKNOWLEDGEMENTS

Core and petrophysical data were provided by Burlington Resources, Seeley Oil Company, Wexpro Company, and PetroCorp, Inc. Geophysical well logs were correlated by Craig D. Morgan, Utah Geological Survey (UGS). Technical oversight and support was provided by the Ute Mountain Ute Indian Tribe. Data entry was conducted by Carolyn Olsen, UGS. Jim Parker of the UGS, drafted figures. The report was reviewed by David Tabet and Mike Hylland of the UGS. Cheryl Gustin, UGS, formatted the manuscript for publication.

REFERENCES

Crawley-Stewart, C.L., and Riley, K.F., 1993, Cherokee, *in* Hill, B.G., and Bereskin, S.R., editors, Oil and gas fields of Utah: Utah Geological Association Publication 22, non-paginated.

Ghazal, R.L., 1978, Desert Canyon, *in* Fassett, J.E., editor, Oil and gas fields of the Four Corners area: Four Corners Geological Society, v. 1, p. 116-117.

Harr, C.L., 1996, Paradox oil and gas potential of the Ute Mountain Ute Indian Reservation, *in* Huffman, A.C., Jr., Lund, W.R., and Godwin, L.H., editors, Geology of the Paradox basin: Utah Geological Association Publication 25, p. 13-28.

Harry, D.L., and Mickus, K.L., 1998, Gravity constraints on lithopheric flexure and the structure of the late Paleozoic Ouachita orogen in Arkansas and Oklahoma south-central North America: Tectonics, v. 17, no. 2, p. 187-202.

Hintze, L.F., 1993, Geologic history of Utah: Brigham Young University Studies Special Publication 7, 202 p.

Hite, R.J., Anders, D.E., and Ging, T.G., 1984, Organic-rich source rocks of Pennsylvanian age in the Paradox Basin of Utah and Colorado, *in* Woodward, Jane, Meissner, F.F., and Clayton, J.L., editors, Hydrocarbon source rocks of the greater Rocky Mountain region: Rocky Mountain Association of Geologists Guidebook, p. 255-274.

Kluth, C.F., 1986, Plate tectonics of the Ancestral Rocky Mountains: American Association of Petroleum Geologists Memoir 41, p. 353-369.

Kluth, C.F., and Coney, P.J., 1981, Plate tectonics of the Ancestral Rocky Mountains: Geology, v. 9, p. 10-15.

Martin, G.W., 1983, Bug, *in* Fassett, J.E., editor, Oil and gas fields of the Four Corners area, volume III: Four Corners Geological Society, p. 1073-1077.

Nuccio, V.F., and Condon, S.M., 1996, Burial and thermal history of the Paradox Basin, Utah and Colorado, and petroleum potential of the Middle Pennsylvanian Paradox Formation, *in* Huffman, A.C., Jr., Lund, W.R., and Godwin, L.H., editors, Geology of the Paradox Basin: Utah Geological Association Publication 25, p. 57-76.

Oline, W.F., 1996, Bug, *in* Hill, B.G., and Bereskin, S.R., editors, Oil and gas fields of Utah: Utah Geological Association Publication 22 Addendum, non-paginated.

Utah Division of Oil, Gas and Mining, 2003, Oil and gas production report, May: non-paginated.

APPENDIX A

POROSITY AND PERMEABILITY CORE-PLUG DATA, CHEROKEE AND BUG FIELDS, SAN JUAN COUNTY, UTAH, AND LITTLE UTE AND SLEEPING UTE FIELDS, MONTEZUMA COUNTY, COLORADO

CHEROKEE FED 22-14

DEPTH	POROSITY	PERM	DEPTH	POROSITY	PERM
768-69	22.9	215	5826-27	23.9	7.6
5769-70	22.1	45	5827-28	17.1	4.5
5770-71	26.8	157	5828-29	17.8	2.3
5771-72	11.1	11	5829-30	19	4.9
5772-73	8.7	10	5830-31	2.3	0.04
5774-75	17.9	9	5831-32	6.8	0.63
5775-76	8.6	3.2	5832-33	14.6	3.9
5776-77	3	0.34	5833-34	14.7	4.7
5777-78	12.3	0.93	5834-35	12.6	4.9
5778-79	15.4	1.4	5835-36	5.5	0.52
5779-80	12.2	2.5	5836-37	9	2.3
5780-81	18.9	5.9	5837-38	6.6	1
5781-82	14.9	11	5838-39	7	2.5
5782-83	26	40	5839-40	8.6	2.7
5783-84	21.9	21	5840-41	9.1	0.91
5784-85	23.3	29	5841-42	10.2	0.93
5785-86	22.7	29	5842-43	6.3	1.6
7586-87	22.9	28	5843-44	8.3	2.8
5787-88	18.6	13	5844-45	6.6	3.5
5789-90	15.5	7.4	5845-46	6.7	12
5790-91	12.2	2	5846-47	10.1	0.97
5791-92	14.1	3.1	5847-48	6.6	0.79
5792-93	10.8	2	5848-49	8.6	1.2
5793-94	12.1	2.4	5849-50	6.1	1.4
5794-95	9.7	1.7	5850-51	9	2.6
5795-96	9.6	1.5	5851-52	10.9	3.1
5796-97	4.9	0.86	5852-53	8.2	1.2
5797-98	4.6	0.26	5853-54	6.9	1.5
5798-99	7.9	0.79	5854-55	6.6	0.74
5799-5800	12.7	3.4	5855-56	7.2	1.6
5800-01	20.1	16	5856-57	8.8	1.6
5801-02	18.4	8.3	5857-58	7.2	1.6
5802-03	9.6	2.7	5858-59	12.4	3.5
5803-04	19.1	2.3	5859-60	15.2	3
5804-05	16	6.5	5860-61	15.5	2.1
5807-08	18.3	4.3	5861-62	12.8	17
5808-09	18.6	7.9	5862-63	11	0.15
5809-10	17.3	5.1	5863-64	10.7	0.13
5810-11	19.9	11	5864-65	11.2	0.1
5811-12	17.1	3	5865-66	2.4	0.03
5812-13	20	6.8	5866-67	2.9	0.03
5813-14	19.8	3.5	5867-68	6.4	0.04
5814-15	23.9	19	5868-69	5.2	0.04
5815-16	23.1	6.6	5869-70	3.5	0.02
5816-17	22.8	15	5870-71	4.4	0.02
5817-18	15.9	14	5871-72	4	0.05
5818-19	9.8	6.1	5872-73	5.7	0.07
5819-20	6	1.1	5873-74	6.2	0.33
5820-21	4.2	0.7	5874-75	5.5	0.13
5821-22	4.6	0.79	5875-76	4.8	0.03
5822-23	2.5	0.34	5877-78	5.4	0.06
5823-24	4.1	1.1	5878-79	2.9	0.02
5824-25	4.2	2.2	5879-80	0.7	0.04
5825-26	18.7	8.2			

	CHEROKEE 33-14	
DEPTH	PERM	POROSITY
5773-74	11	19.1
5774-75	24	21.2
5775-76	12	15.2
5776-77	12	19.4
5777-78	37	21.9
5778-79	30	19
5779-80	12	17.1
5780-81	17	15.8
5781-82	103	23.6
5782-83	18	17.4
5783-84	17	15.8
5791-92	3.26	2.2
5792-93	0.77	1
5793-94	0.27	0.8
5794-95	0.73	1.2
5795-96	0.18	0.9
5796-97	0.8	1.7
5797-98	0.22	1.5
5798-99	0.05	2.2

	BUG 4	
DEPTH	PERM	POROSITY
6284-85	2.5	6.9
6285-86	5.9	7.8
6286-87	0.81	5.7
6287-88	86	12.5
6288-89	64	13.7
6289-90	92	14.5
6290-91	39	14.4
6291-92	56	13
6292-93	51	16.1
6293-94	41	14.2
6294-95	87	13.5
6295-96	39	11.9
6296-97	27	10.2
6297-98	18	10.5
6298-99	7.2	8.2
6299-6300	7.8	8.4
6300-01	1.3	5.2

	BUG 2 MAY	
DEPTH	PERM	POROSITY
6298-99	270	4.8
6299-6300	24	7.6
6300-01	25	4.4
6301-02	34	8.4
6302-03	88	10.4
6303-04	28	11.2
6304-05	99	10.9
6305-06	75	11.5
6306-07	60	10.6
6307-08	54	10.8
6308-09	49	13.6
6309-10	73	14.2
6310-11	71	15.6
6311-12	31	14.5
6312-13	30	14.9
6313-14	20	13.4
6314-15	10	12.6
6315-16	5.7	10.3
6316-17	0.27	5.7
6317-18	0.02	3.2
6318-19	0.03	4.8
6322-23	0.06	3.6
6323-24	0.49	1.5
6324-25	0.01	2.7
6325-26	16	3
6326-27	19	2.1
6327-28	0.04	2.2

	BUG 10	
DEPTH	PERM	POROSITY
6319-20	0.19	6.5
6320-21	0.33	6
6321-22	0.07	3.4
6322-23	4.9	5.7
6323-24	62	7.7
6324-25	7	8.5
6325-26	16	10.4
6326-27	6.2	8.7
6327-28	7.5	10.5
6328-29	10	7.6
6329-30	0.4	5
6330-31	0.01	0.5
6331-32	0.01	3.6
6332-33	0.01	1.3
6333-34	0.6	0.9
6334-35	0.01	0.8
6335-36	0.01	3.1
6336-37	8.6	5.2
6337-38	4.1	4.8
6338-39	0.14	3.8
6339-40	0.01	0.9
6340-41	0.02	0.4
6341-42	0.08	1.3

BUG 13		
DEPTH	PERM	POROSITY
5926-27	0.01	1.8
5927-28	0.01	6.7
5928-29	3.4	15.4
5929-30	5.3	15.5
5930-31	15	9.3
5931-32	5.5	11
5932-33	6.7	10.5
5933-34	24	11.1
5934-35	0.12	13.3
5935-36	14	11.9
5936-37	4.4	12
5937-38	5.7	12.7
5938-39	0.01	10
5939-40	6.9	12
5940-41	11	15.1
5941-42	1.8	8.57
5942-43	1.1	7.4
5943-44	0.01	5.1
5944-45	0.01	4.6

BUG 16		
DEPTH	PERM	POROSITY
6295-96	0.7	12.9
6296-97	0.8	4.5
6297-98	16	6.7
6298-99	59	12.6
6299-6300	3.4	10.3
6300-01	76	15.9
6301-02	28	12.2
6302-03	2.3	9.6
6305-06	59	13.3
6313-14	28	14.8
6314-15	14	13.8
6315-16	0.3	7.7
6316-17	3.7	8
6317-18	0.05	4.1

BUG 7-A		
DEPTH	PERM	POROSITY
6357-58	0.01	1.7
6358-59	0.03	4.2
6359-60	0.01	4.3
6360-61	0.02	5.8
6361-62	0.01	3.9
6362-63	0.01	1.3
6363-64	0.01	2.1

SLEEPING UTE #1		
DEPTH	PERM	POROSITY
5598.0	0.385	3
5599.3	1.3	2.5
5600.9	0.241	7.1
5602.3	0.398	6.5
5617.7	0.014	3.8
5618.7	0.935	4.3
5620.3	0.049	7.7
5621.3	0.097	9.8
5623.3	0.06	8.6
5623.8	0.046	7.2
5626.9	0.796	13.4
5632.4	0.513	12.1
5635.6	0.042	6.2
5636.6	0.08	8
5637.7	0.083	8.1
5639.2	0.116	6.5
5640.3	0.042	3.7
5649.8	0.015	2.2

LITTLE UTE #1

DEPTH	PERM	POROSITY	DEPTH	PERM	POROSITY
5836.2	0.409	15.4	5896.2	10.5	15.9
5837.8	2.87	20.5	5897.1	0.008	1.6
5838.9	0.009	4.3	5899.3	0.087	9.6
5839.7	0.049	5.1	5905.3	0.011	7.5
5840.8	0.025	5.6	5912.1	0.312	1.2
5842.1	10	4.7	5913.3	0.706	3.1
5842.9	0.173	6.4	5914.5	0.933	4.7
5843.9	0.022	4.8	5915.6	1.04	3.4
5844.4	0.102	8.7	5916.9	5.05	6.6
5845.6	4.86	16.4	5919.2	0.476	4.5
5846.7	0.475	12.8	5920.7	0.673	2.8
5847.9	0.631	9.1	5921.6	6.84	8.1
5848.7	0.329	6.8	5922.3	2.02	5.2
5849.7	0.971	18.5	5923.7	1.98	2.4
5851.8	0.765	14.4	5924.7	1.59	5.1
5852.8	0.71	12.5	5926.3	0.229	3.1
5854.9	4.49	10	5928.2	9.9	6.8
5856.1	0.391	15.6	5929.1	2.86	3.2
5861.9	0.599	18	5930.1	0.563	5
5869.9	4.72	15.7	5931.4	0.139	3.5
5870.9	12.2	9.8	5932.4	0.109	2.5
5871.9	36.4	10.2	5933.4	0.376	3.1
5873.7	0.651	5.6	5934.3	0.32	4.4
5874.5	5.84	10	5935.7	1.27	1.7
5876.2	2.67	9.7	5939.7	0.05	4.3
5877.6	1.43	11.8	5940.5	0.018	4.6
5878.7	5.87	11	5941.5	0.634	3.9
5879.9	3.48	9.1	5942.4	0.237	3.3
5881.2	13.5	11.7	5944.3	fractured	5.4
5882.5	95.6	18.4	5945.5	4.49	6.6
5883.5	3.99	10.2	5946.3	0.881	3.9
5884.3	21.2	11.9	5948.3	2.99	4.6
5885.2	6.76	11.2	5949.0	3.77	6.2
5886.2	1.37	6.8	5951.0	0.647	5.8
5887.4	0.74	8	5951.8	1.03	5.6
	Core No. 2 Ismay Formation		5953.3	0.567	5.4
5888.7	1.36	11.2	5954.7	0.761	5.5

APPENDIX B

POROSITY AND PERMEABILITY CROSS-PLOTS CHEROKEE AND BUG FIELDS, SAN JUAN COUNTY, UTAH

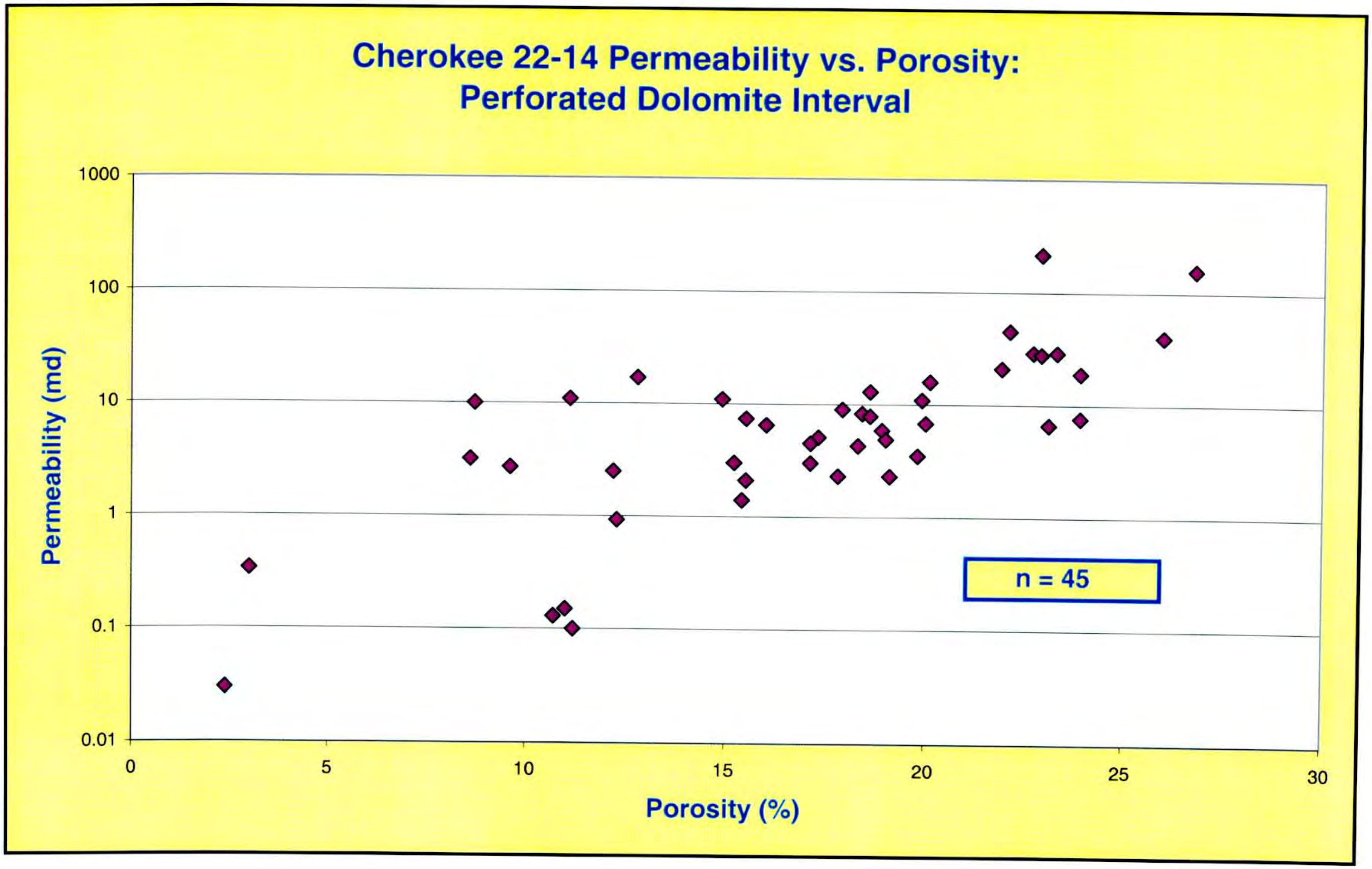

Cherokee 22-14 Permeability vs. Porosity:
Perforated Dolomite Interval
Permeability (md)
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)
n = 45

Figure B-2

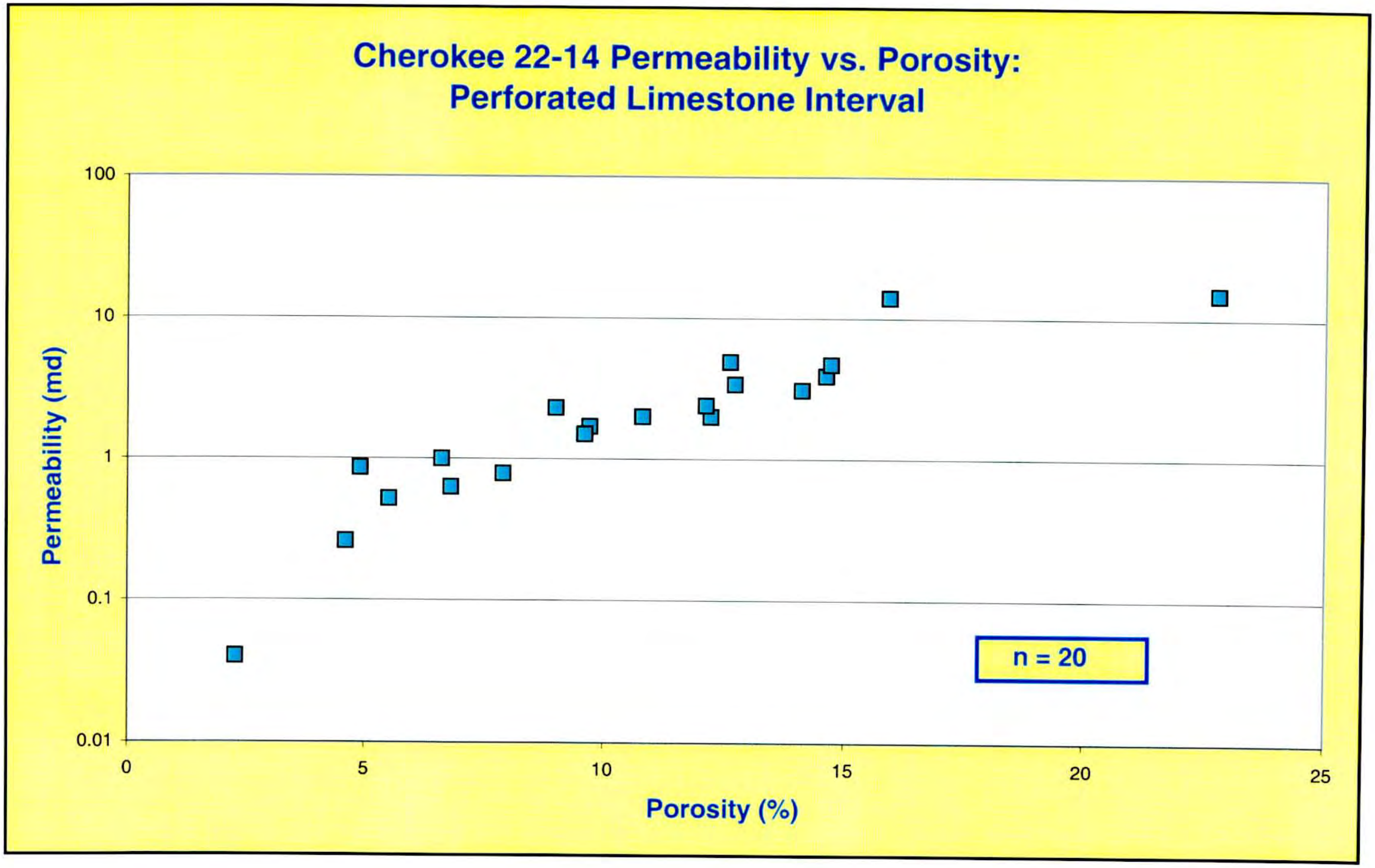

Cherokee 22-14 Permeability vs. Porosity:
Perforated Limestone Interval
Permeability (md)
100
10
1
0.1
0.01
0
5
10
15
20
25
Porosity (%)
n = 20

Figure B-3

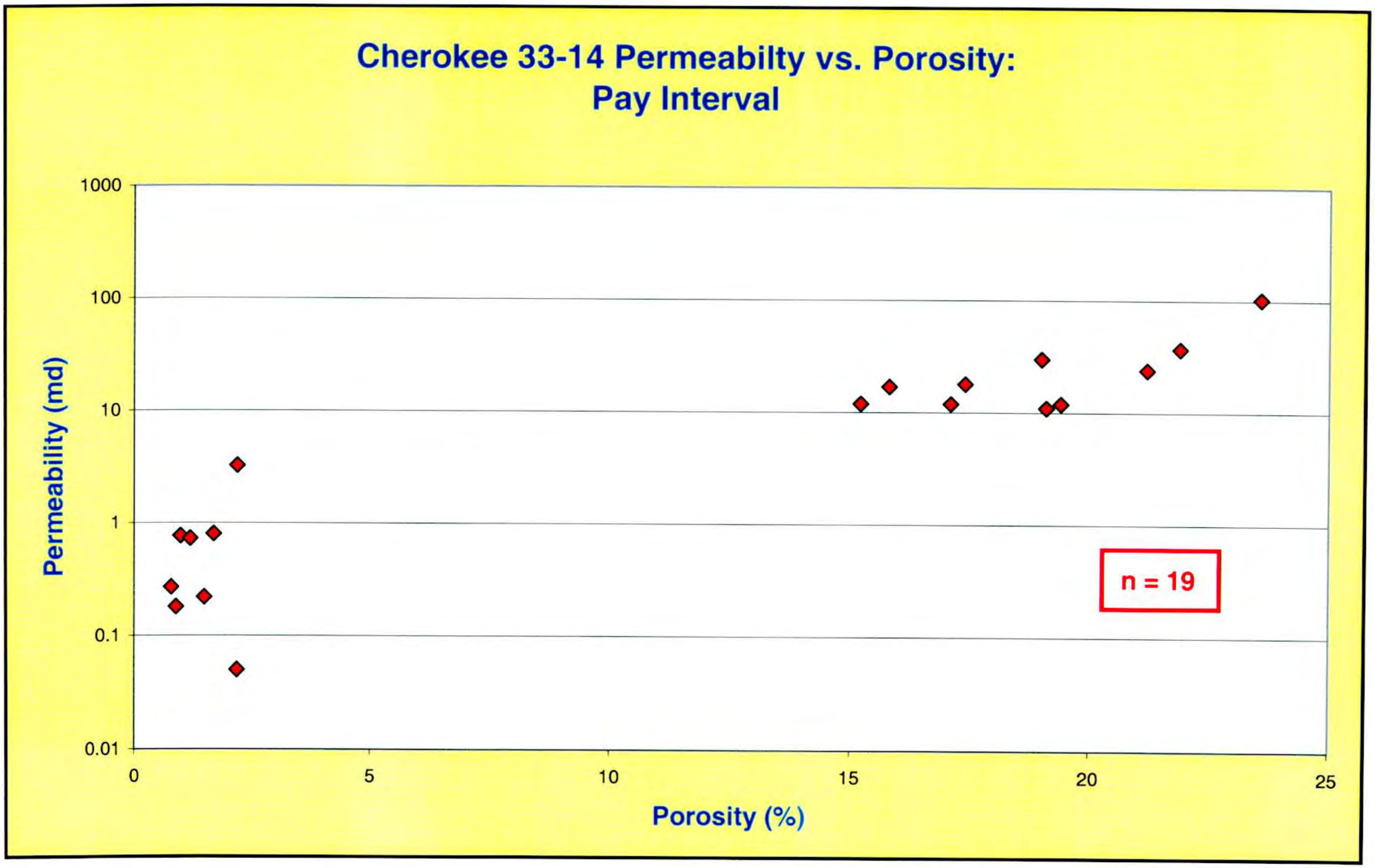

Cherokee 33-14 Permeabilty vs. Porosity:
Pay Interval
Permeability (md)
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
Porosity (%)
n = 19

Figure B-4

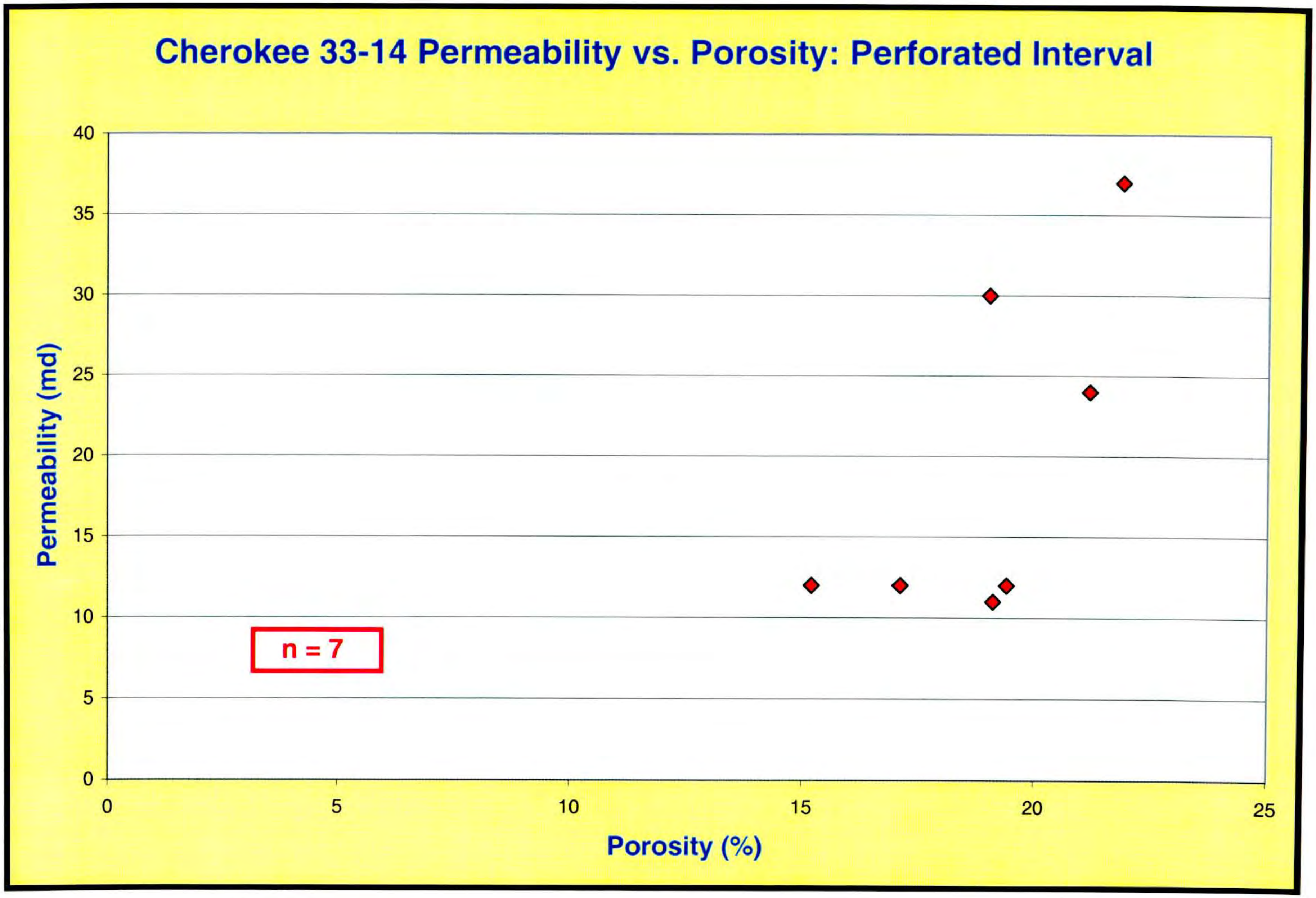

Cherokee 33-14 Permeability vs. Porosity: Perforated Interval
Permeability (md)
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
Porosity (%)
n = 7

Figure B-5

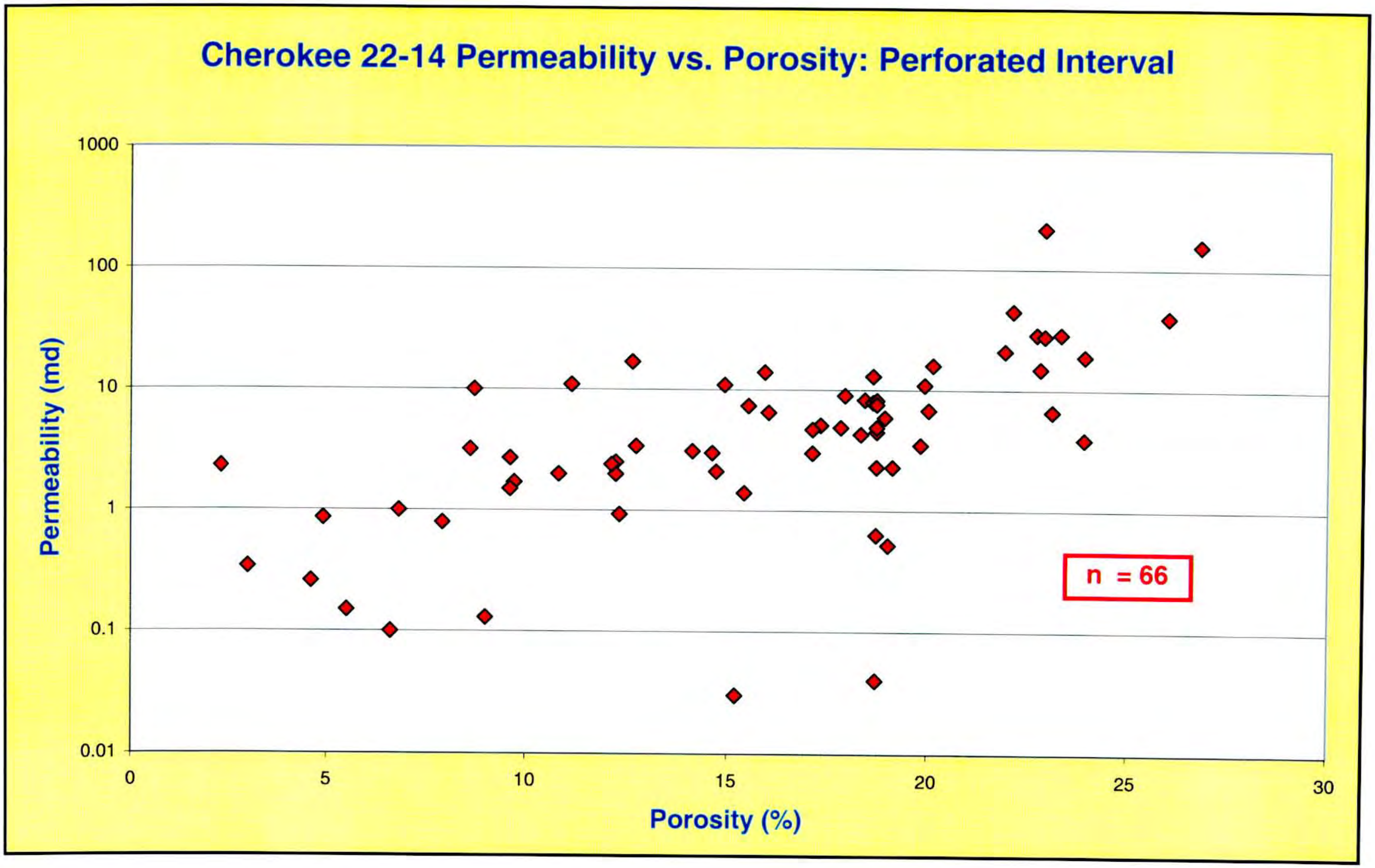

Cherokee 22-14 Permeability vs. Porosity: Perforated Interval
Permeability (md)
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)
n = 66

Figure B-6

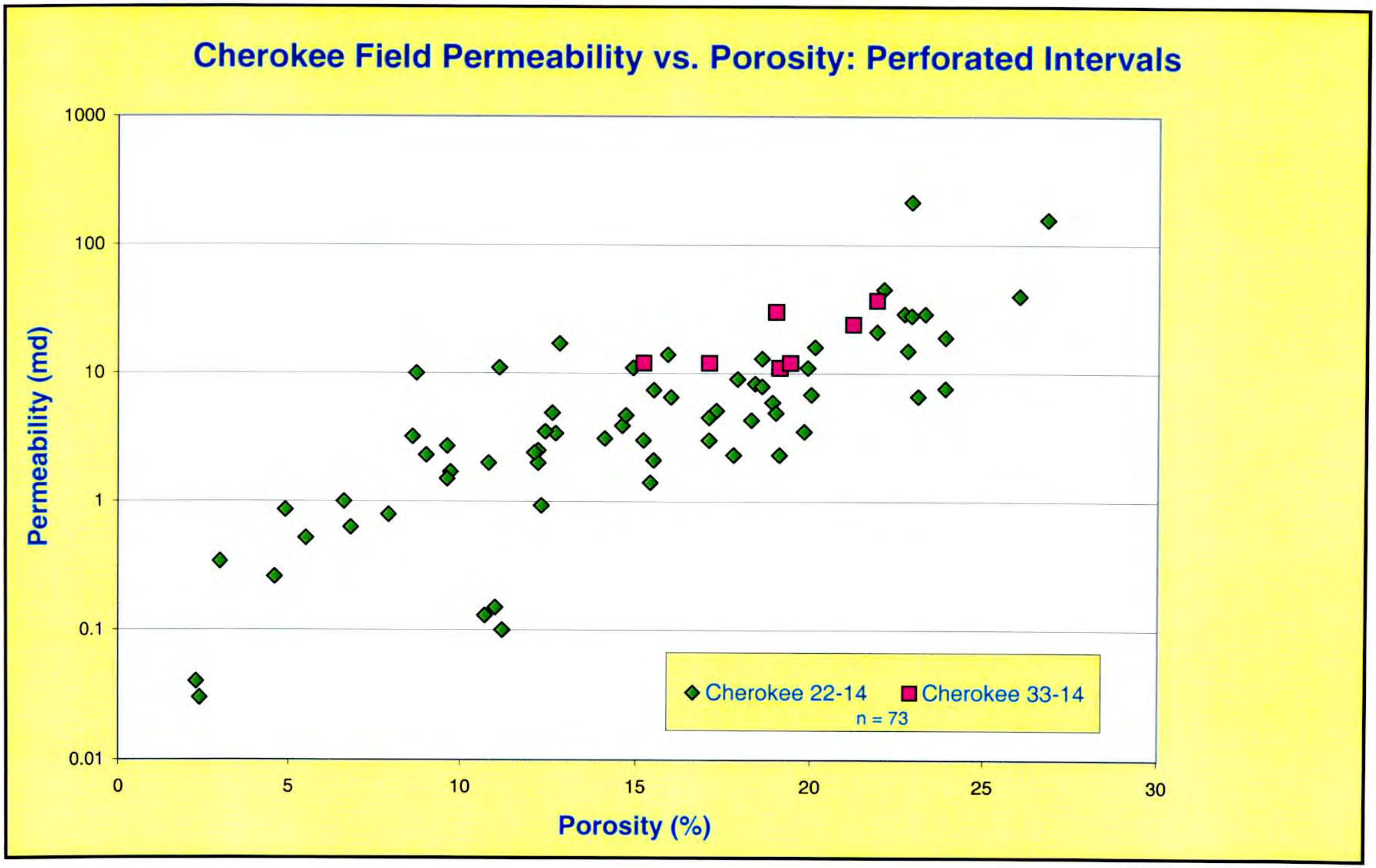
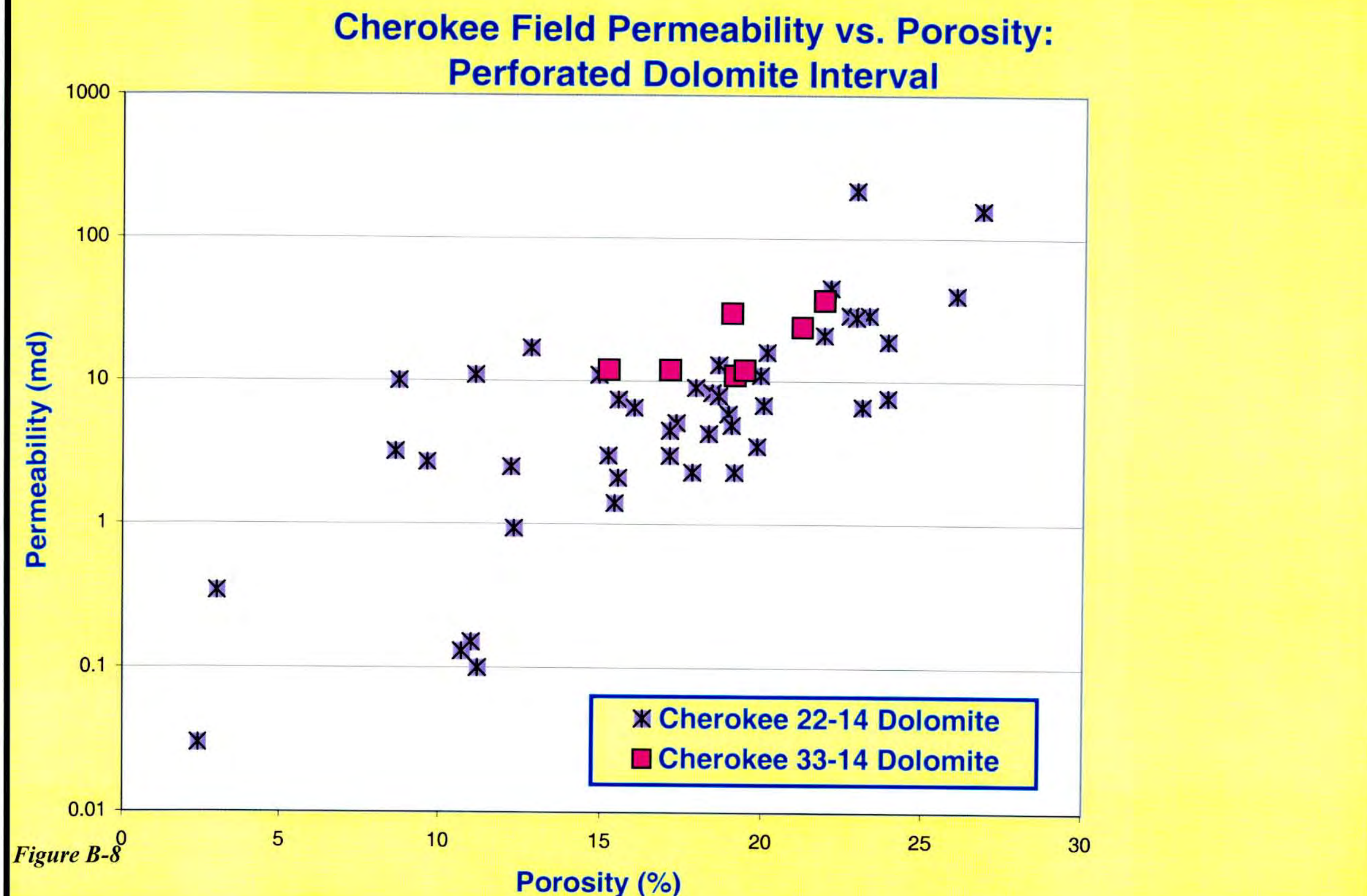

Cherokee Field Permeability vs. Porosity: Perforated Intervals
Permeability (md)
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)
Cherokee 22-14
Cherokee 33-14
n = 73

Figure B-7



Cherokee Field Permeability vs. Porosity:
Perforated Dolomite Interval
Permeability (md)
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)
Cherokee 22-14 Dolomite
Cherokee 33-14 Dolomite

Figure B-8

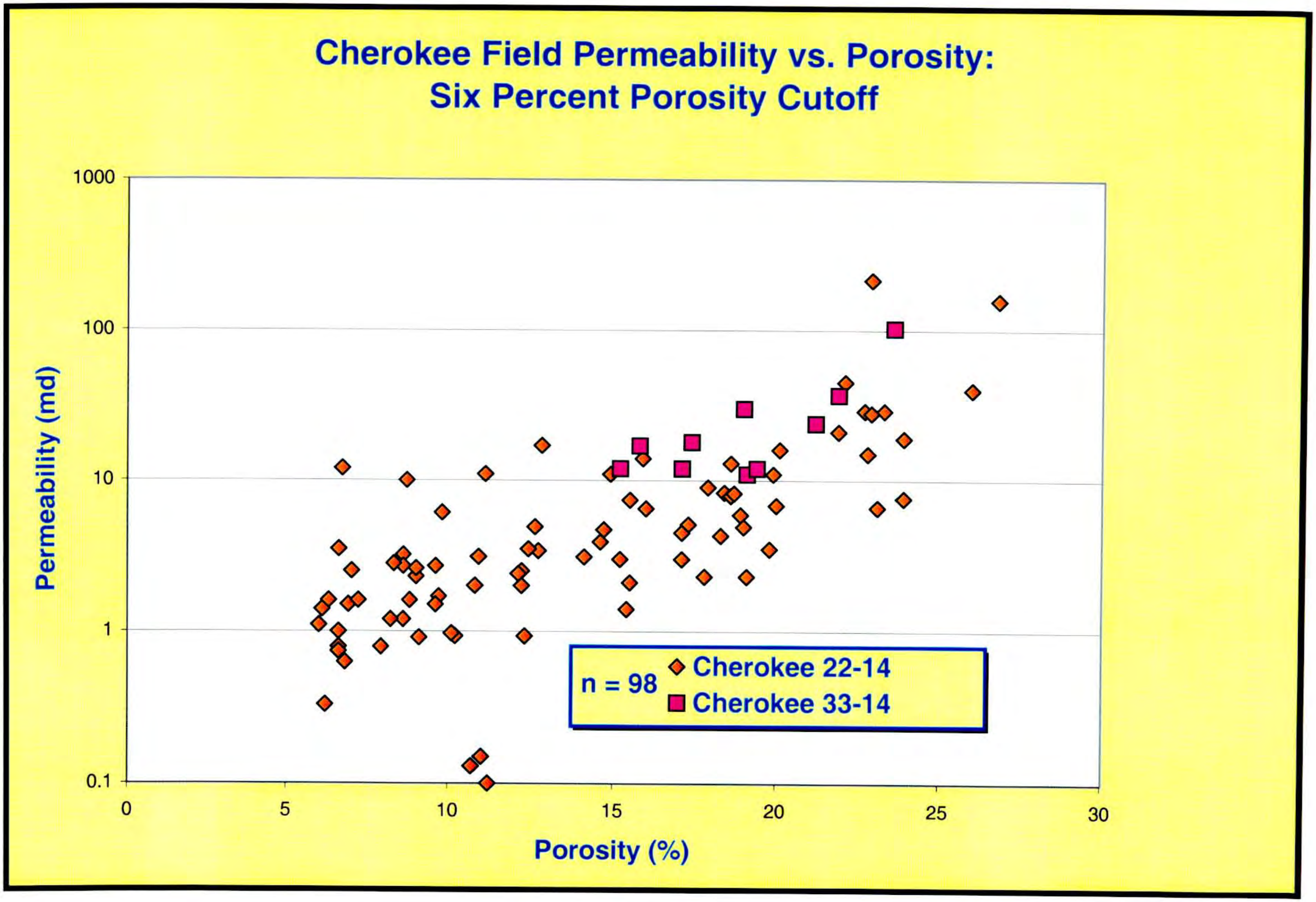

Cherokee Field Permeability vs. Porosity:
Six Percent Porosity Cutoff
Permeability (md)
1000
100
10
1
0.1
0
5
10
15
20
25
30
Porosity (%)
n = 98
Cherokee 22-14
Cherokee 33-14

Figure B-9

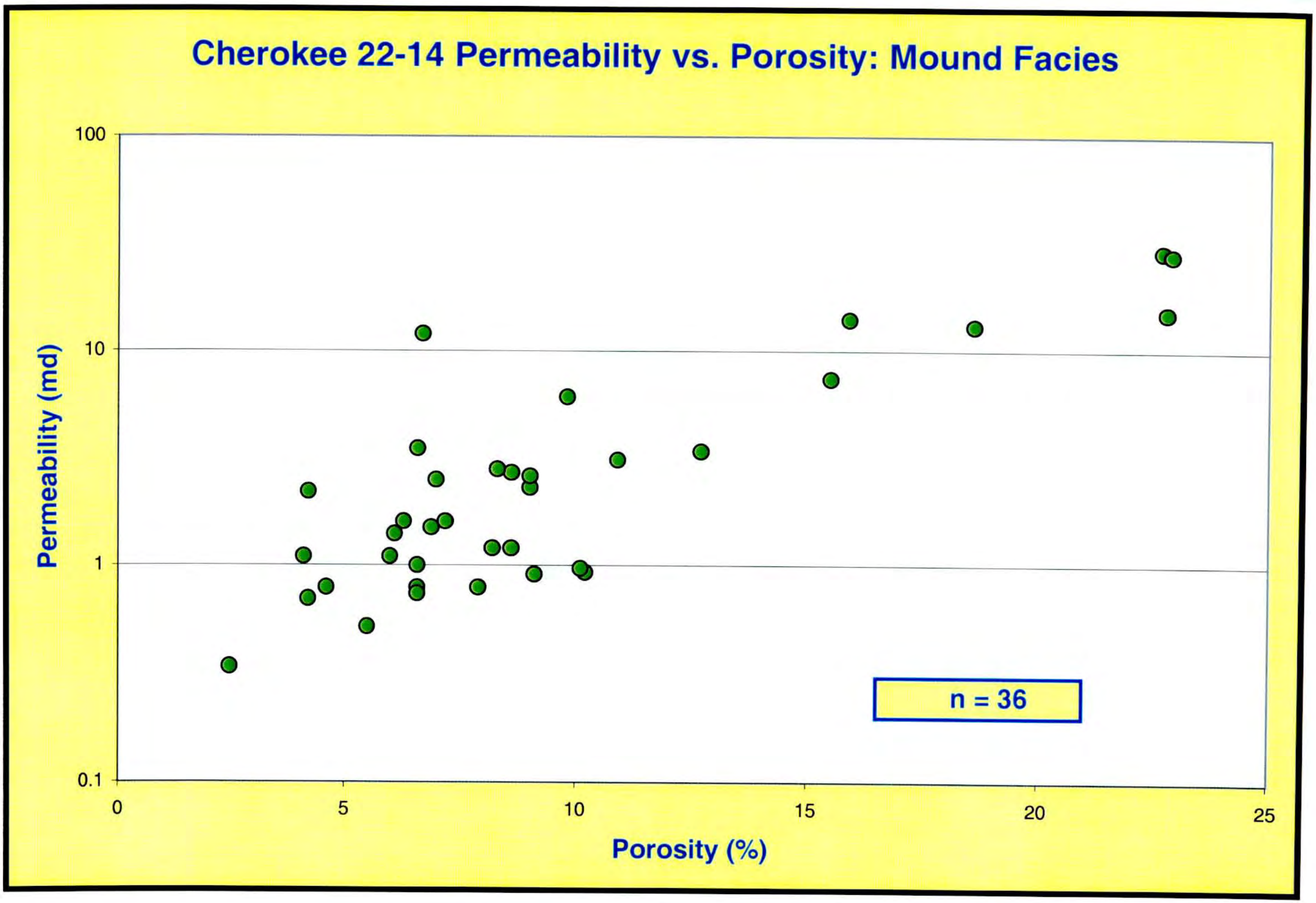

Cherokee 22-14 Permeability vs. Porosity: Mound Facies
Permeability (md)
100
10
1
0.1
0
5
10
15
20
25
Porosity (%)
n = 36

Figure B-10

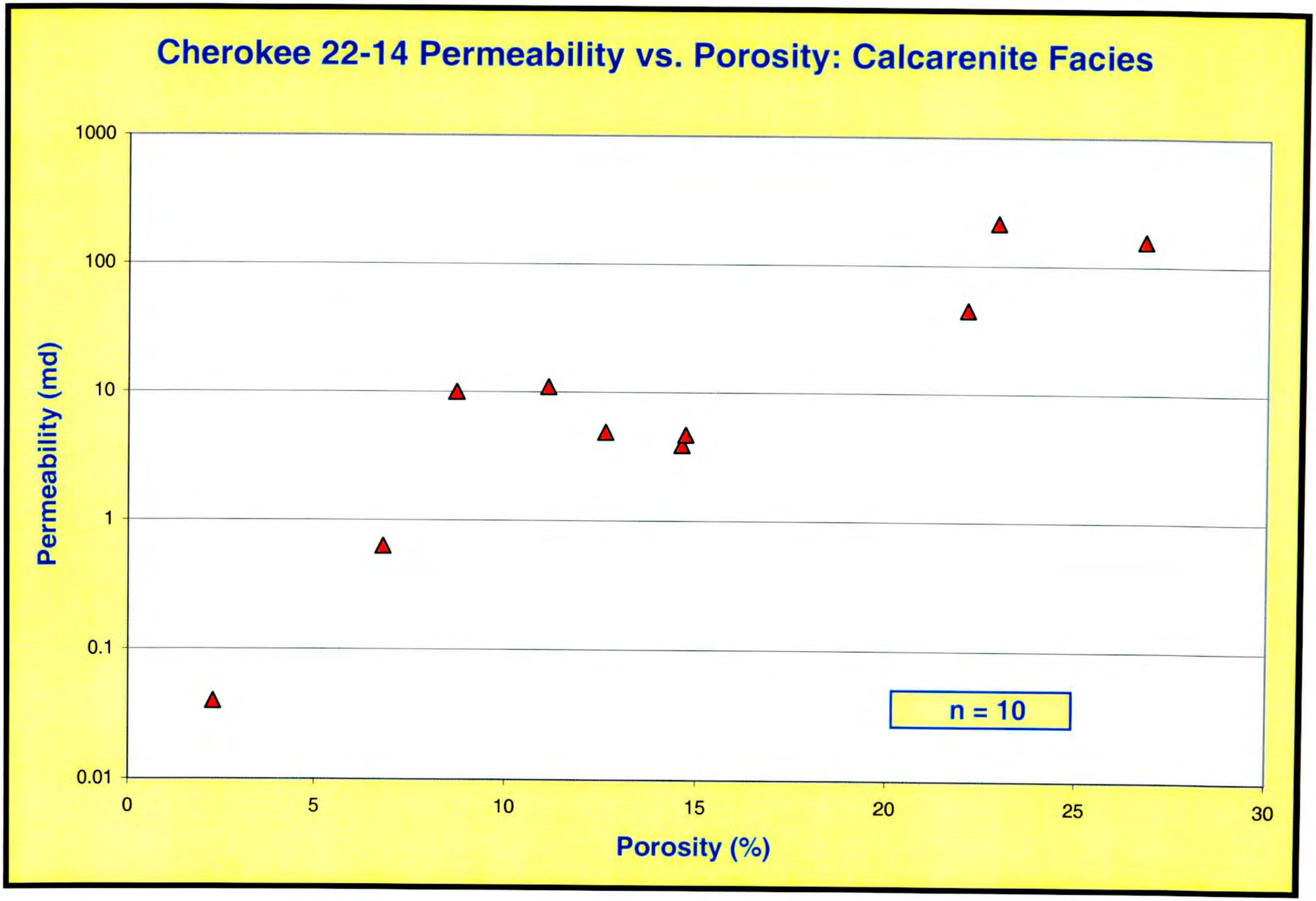

Cherokee 22-14 Permeability vs. Porosity: Calcarenite Facies
Permeability (md)
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)
n = 10

Figure B-11

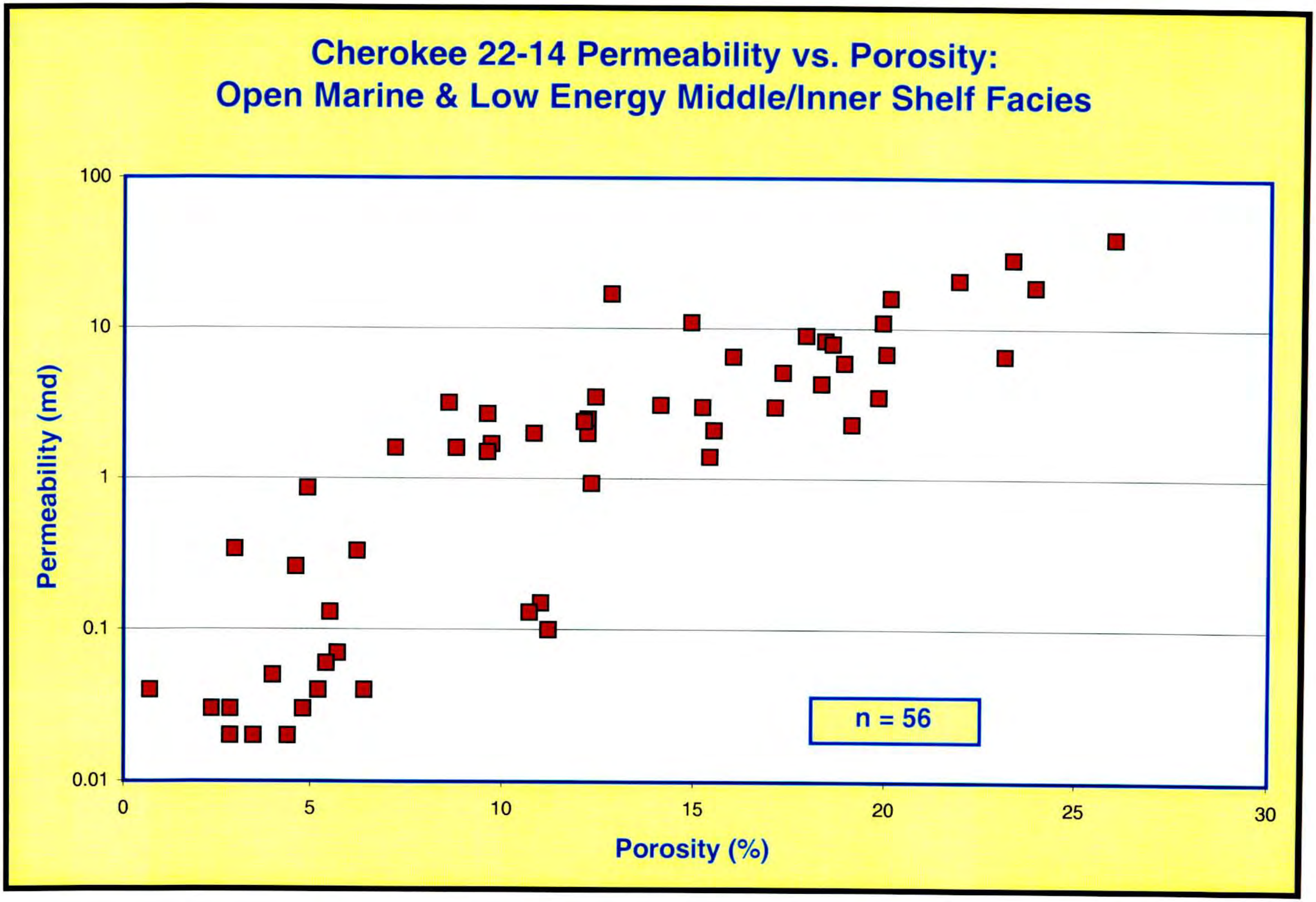
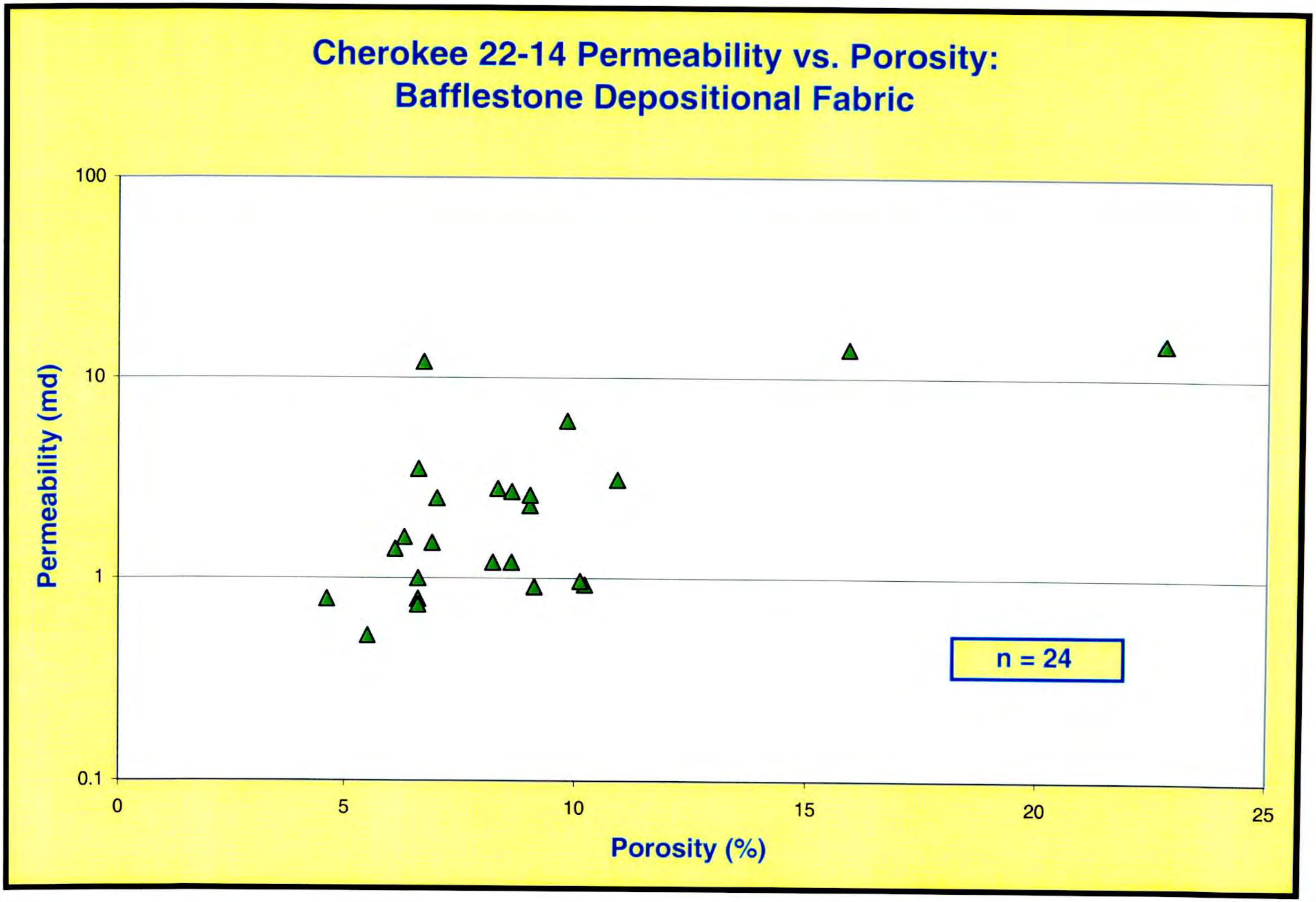
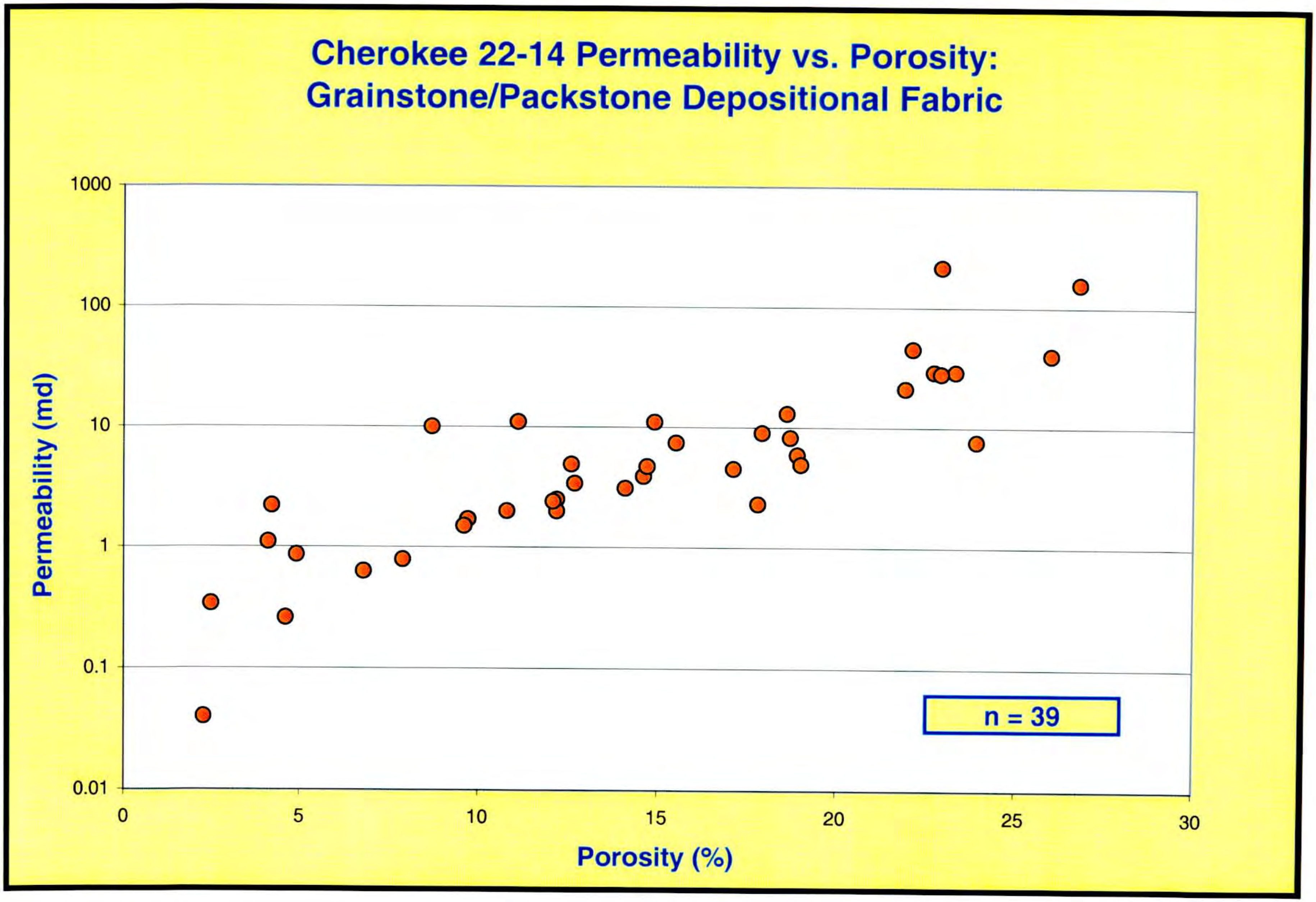

Cherokee 22-14 Permeability vs. Porosity:
Open Marine & Low Energy Middle/Inner Shelf Facies
Permeability (md)
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)
n = 56

Figure B-12



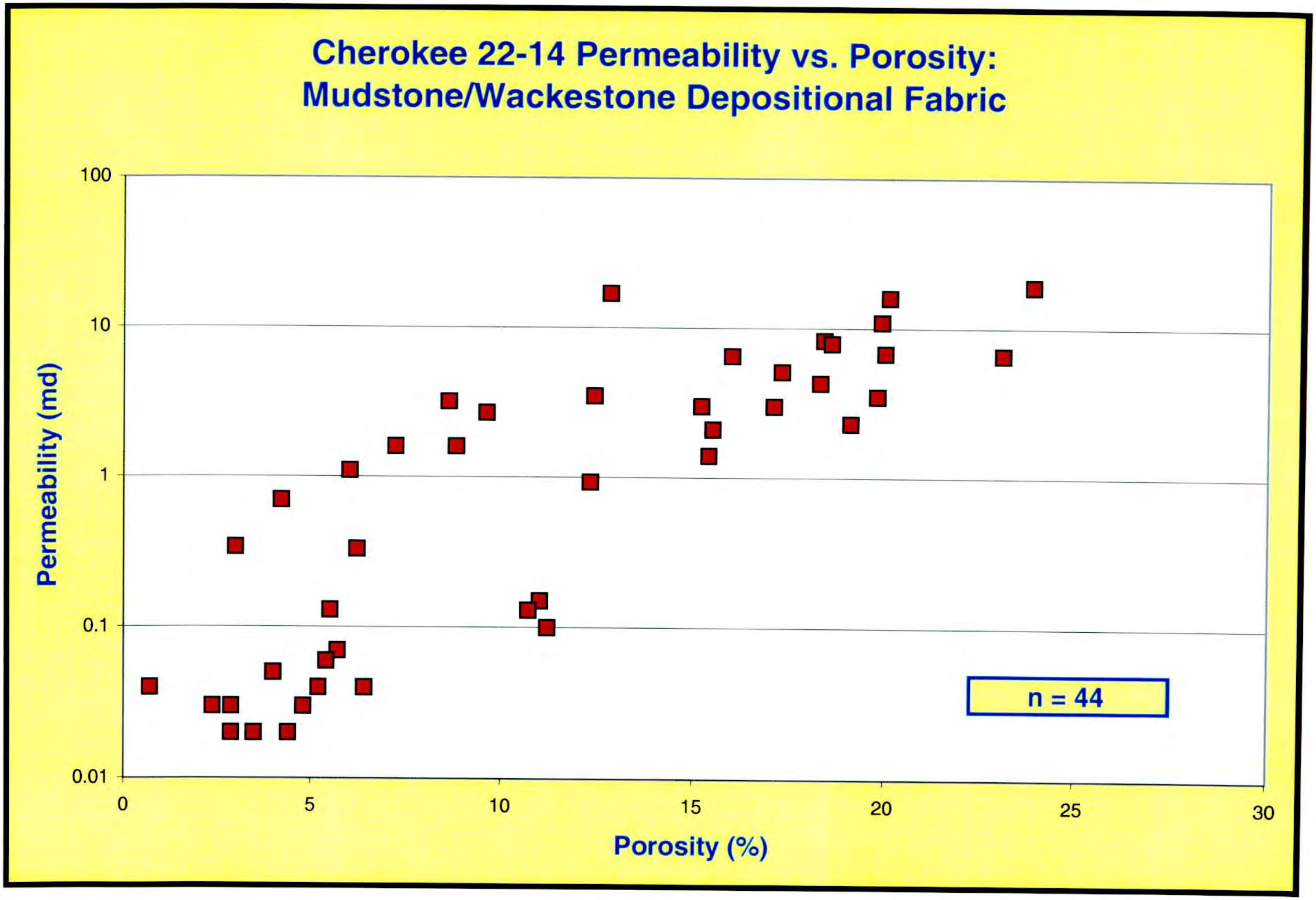
Cherokee 22-14 Permeability vs. Porosity:
Bafflestone Depositional Fabric
Permeability (md)
100
10
1
0.1
0
5
10
15
20
25
Porosity (%)
n = 24

Figure B-13



Cherokee 22-14 Permeability vs. Porosity:
Grainstone/Packstone Depositional Fabric
Permeability (md)
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)
n = 39

Figure B-14



Cherokee 22-14 Permeability vs. Porosity:
Mudstone/Wackestone Depositional Fabric
Permeability (md)
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)
n = 44

Figure B-15

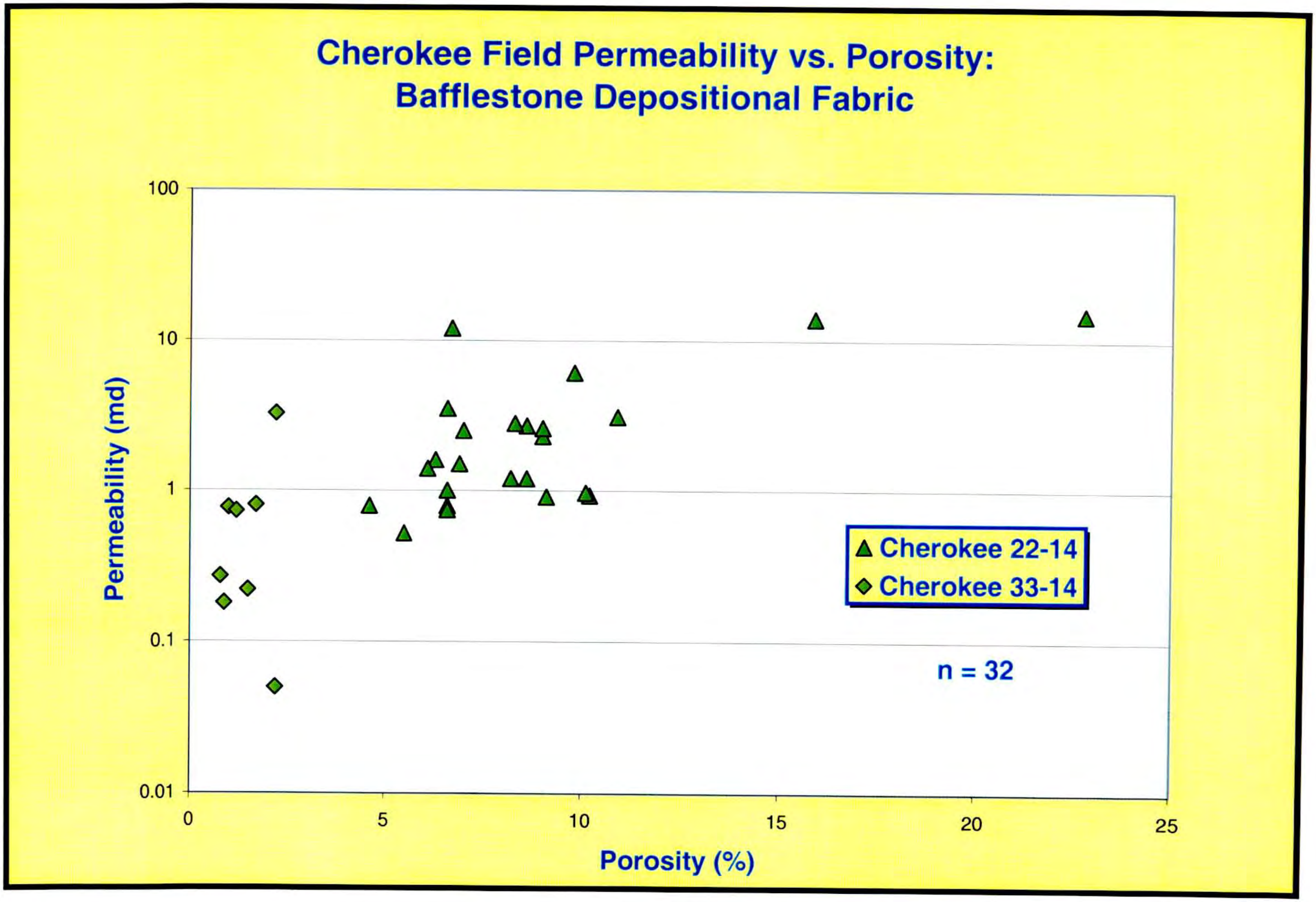

Cherokee Field Permeability vs. Porosity:
Bafflestone Depositional Fabric
Permeability (md)
100
10
1
0.1
0.01
0
5
10
15
20
25
Porosity (%)
Cherokee 22-14
Cherokee 33-14
n = 32

Figure B-16

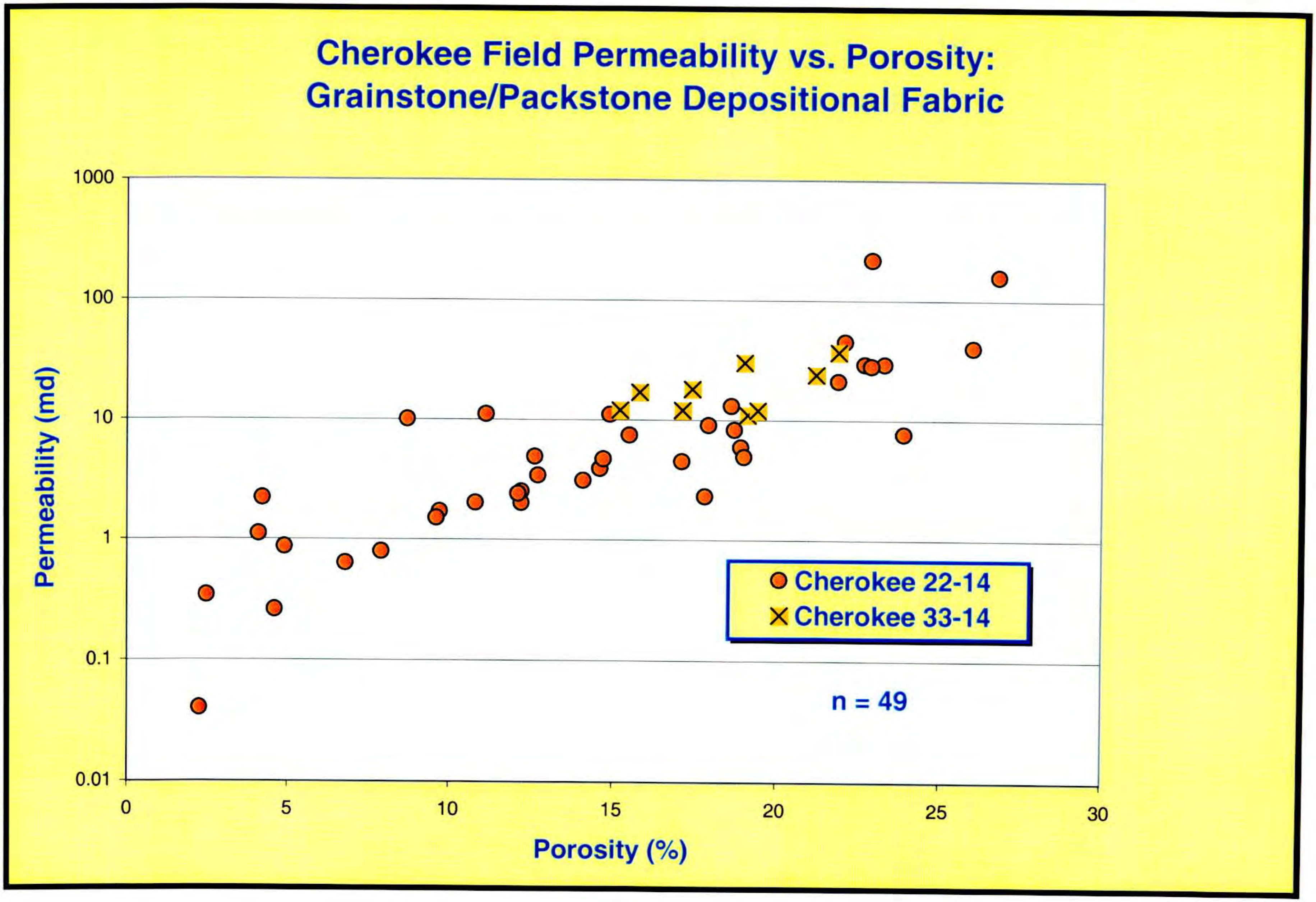

Cherokee Field Permeability vs. Porosity:
Grainstone/Packstone Depositional Fabric
Permeability (md)
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)
Cherokee 22-14
Cherokee 33-14
n = 49

Figure B-17

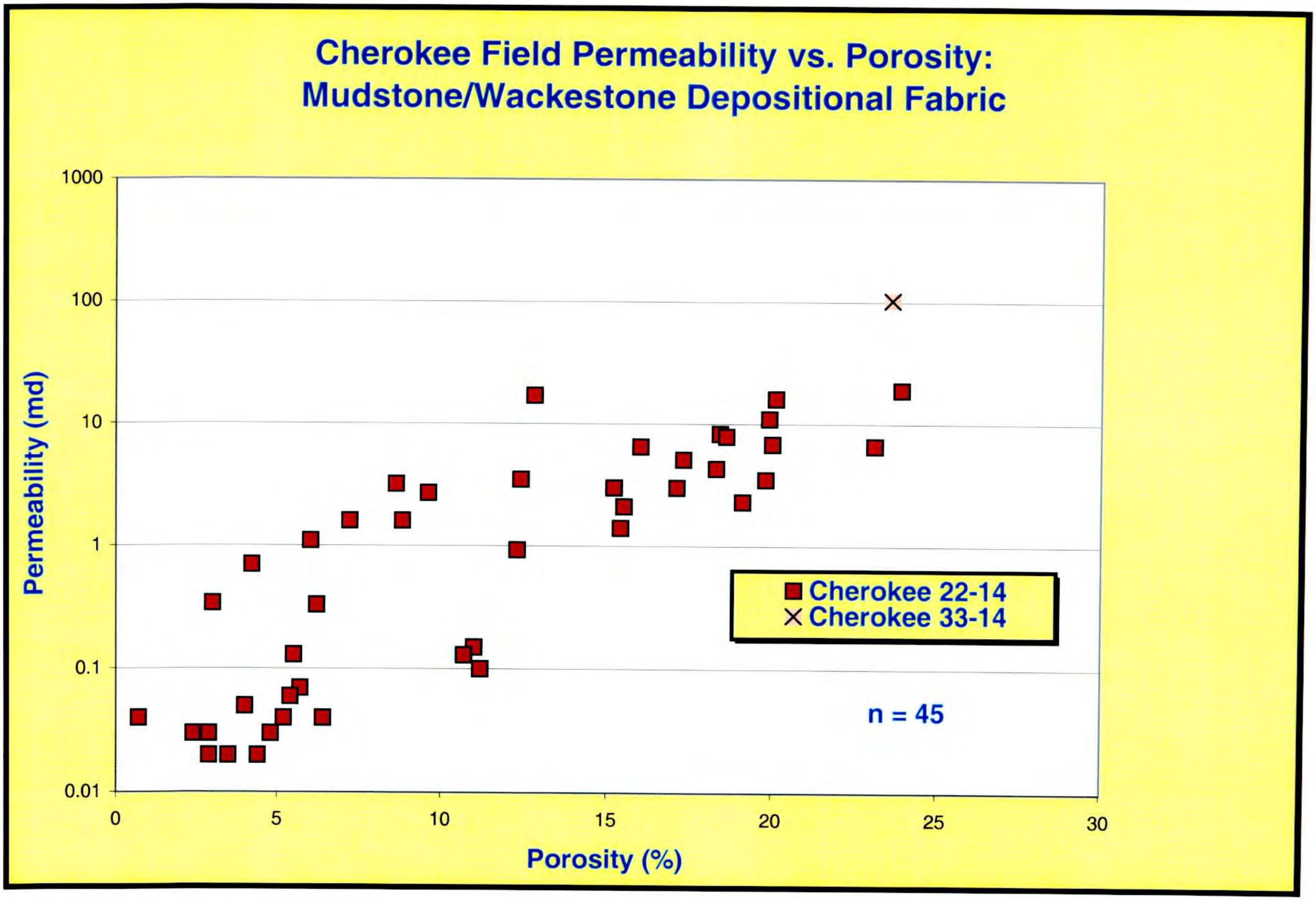
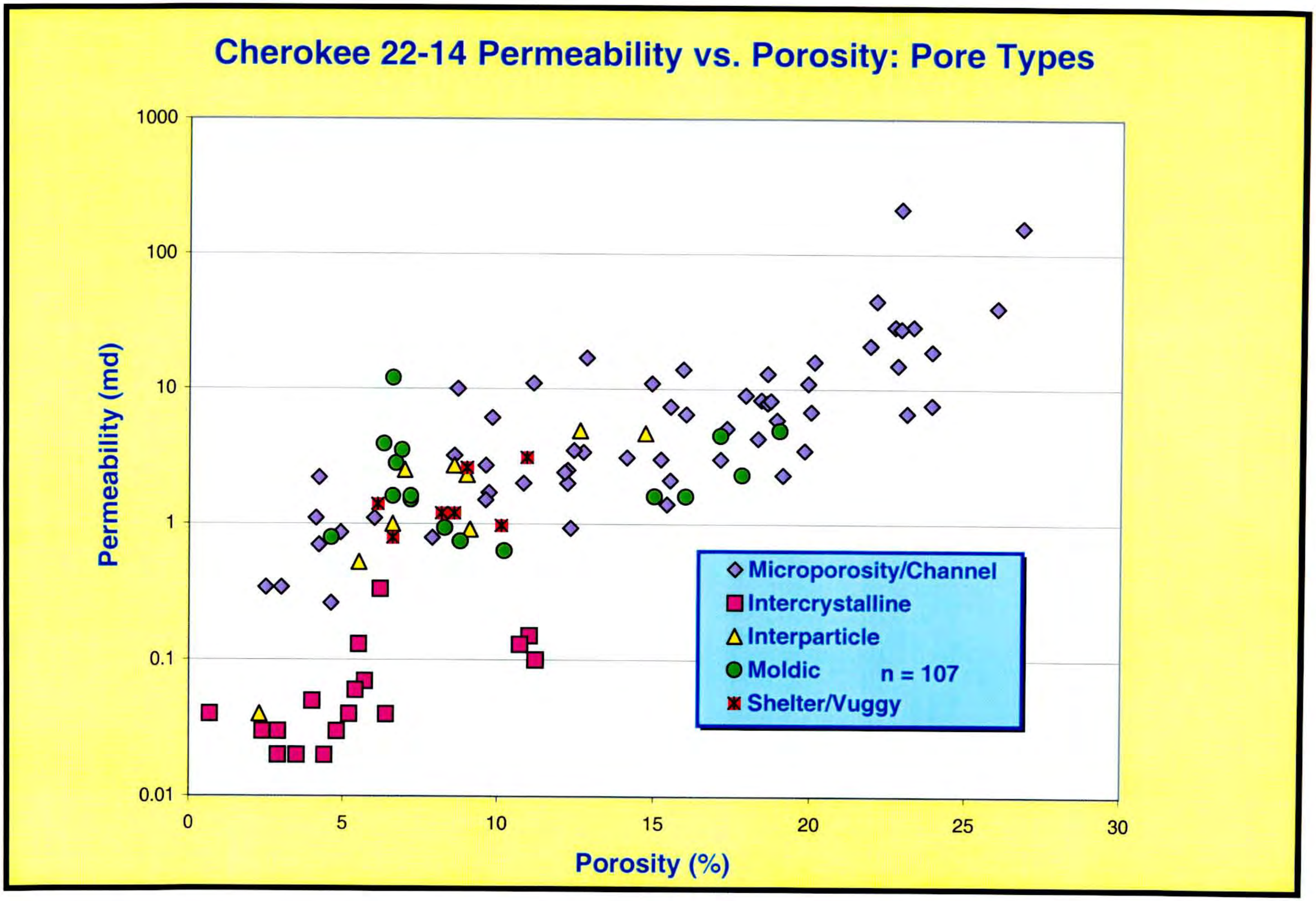

Cherokee Field Permeability vs. Porosity:
Mudstone/Wackestone Depositional Fabric
Permeability (md)
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)
Cherokee 22-14
Cherokee 33-14
n = 45

Figure B-18



Cherokee 22-14 Permeability vs. Porosity: Pore Types
Permeability (md)
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)
Microporosity/Channel
Intercrystalline
Interparticle
Moldic
n = 107
Shelter/Vuggy

Figure B-19

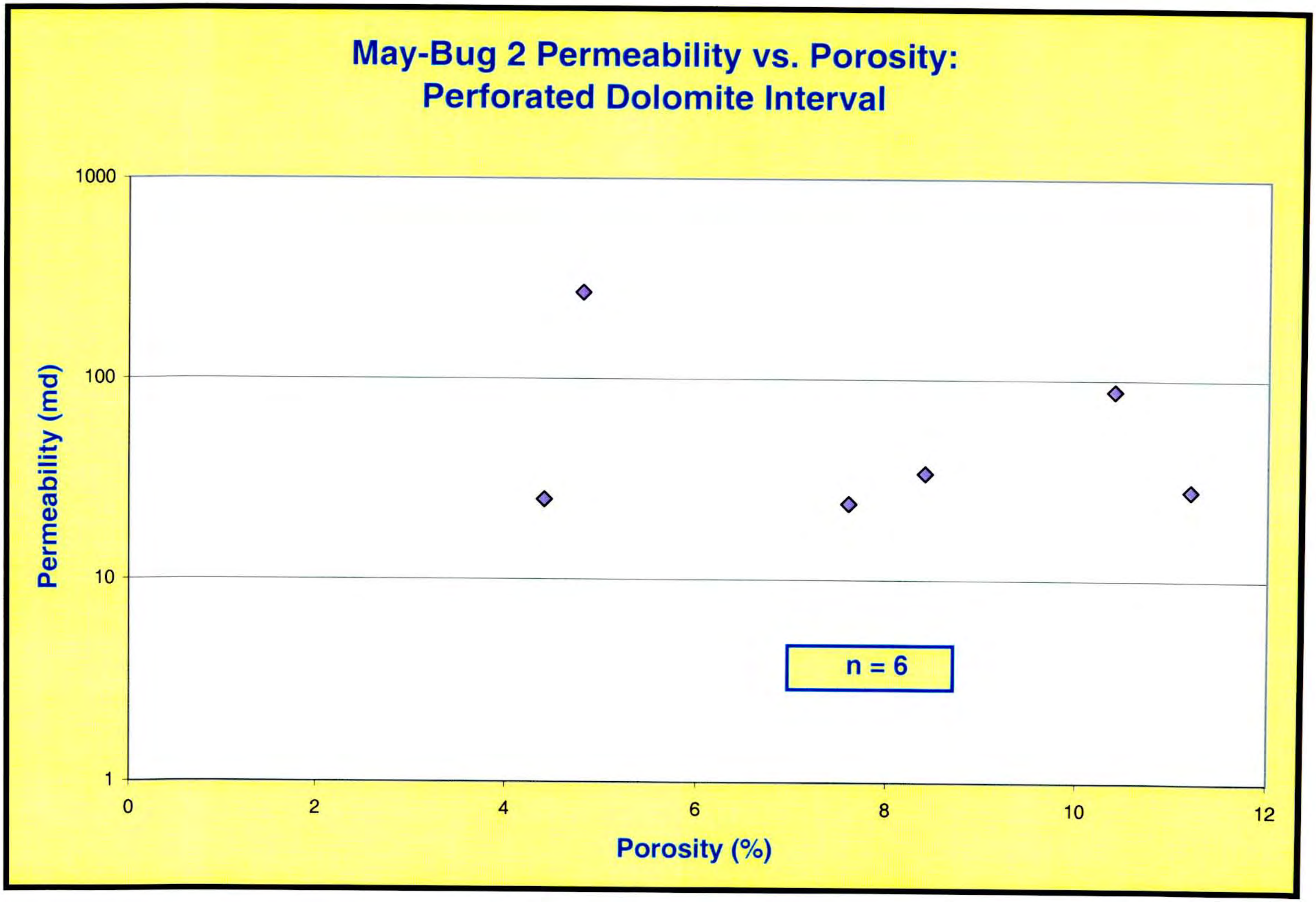
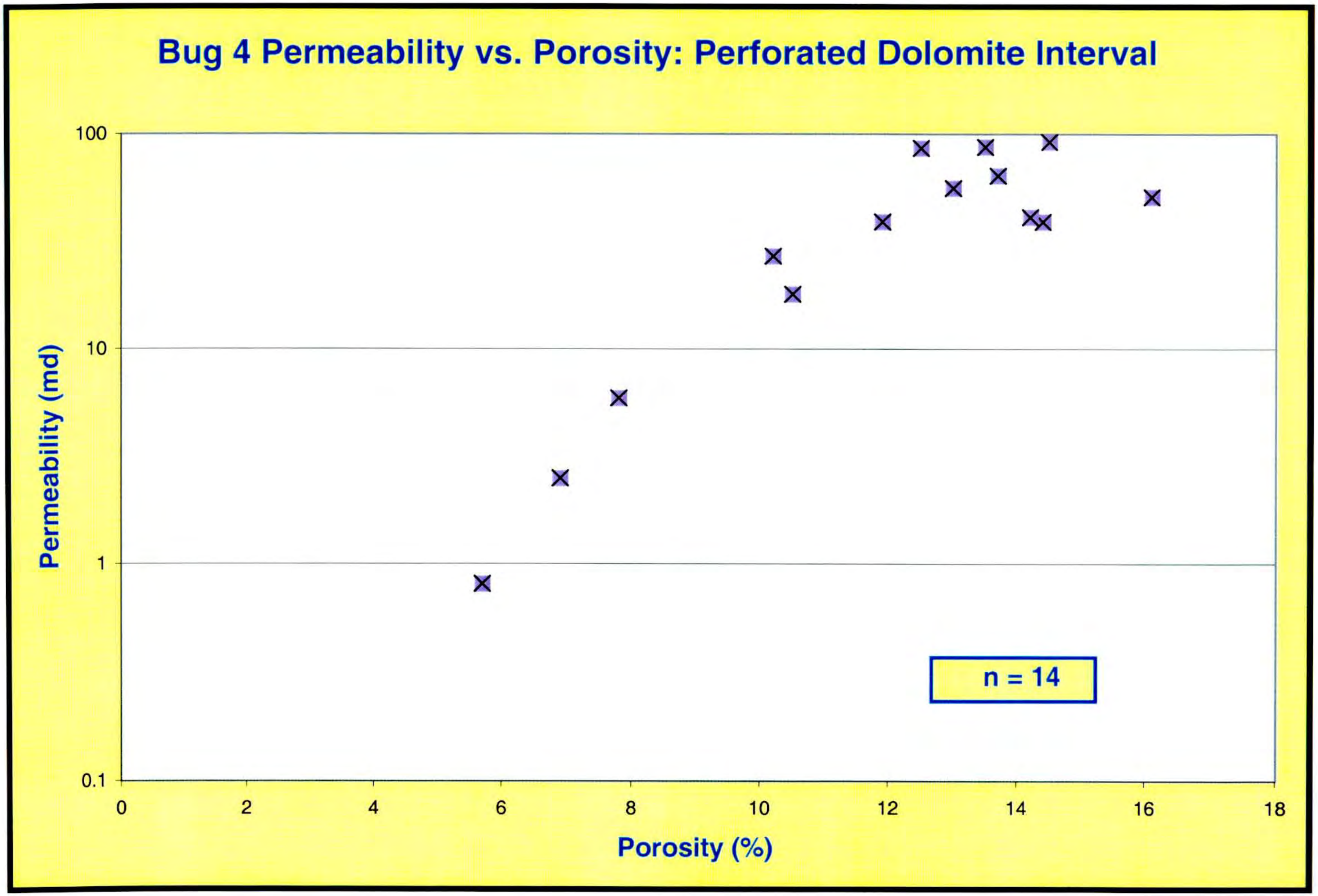

May-Bug 2 Permeability vs. Porosity:
Perforated Dolomite Interval
Permeability (md)
1000
100
10
1
0
2
4
6
8
10
12
Porosity (%)
n = 6

Figure B-20



Bug 4 Permeability vs. Porosity: Perforated Dolomite Interval
Permeability (md)
100
10
1
0.1
0
2
4
6
8
10
12
14
16
18
Porosity (%)
n = 14

Figure B-21

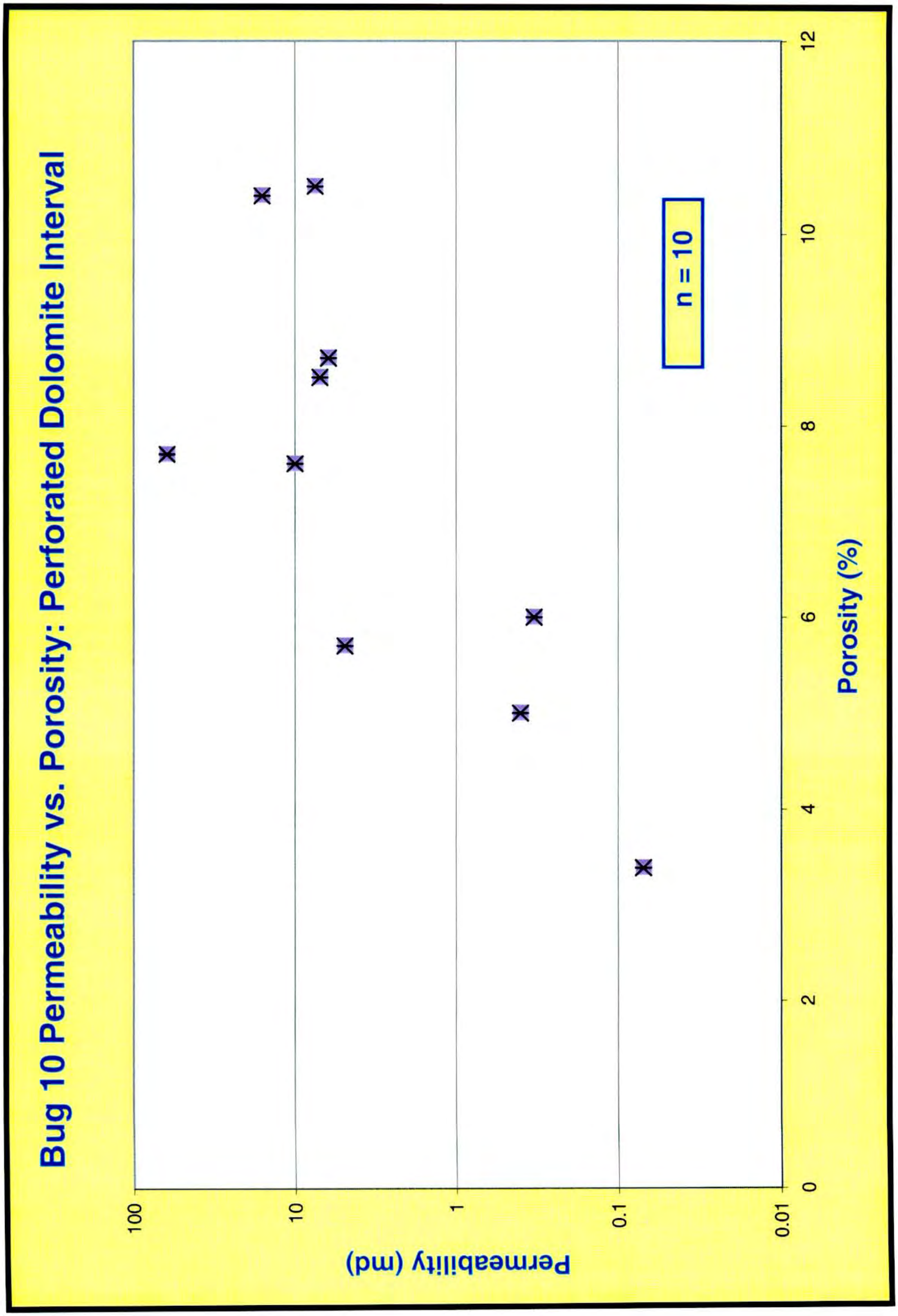

Bug 10 Permeability vs. Porosity: Perforated Dolomite Interval
Permeability (md)
100
10
1
0.1
0.01
0
2
4
6
8
10
12
Porosity (%)
n = 10

Figure B-22

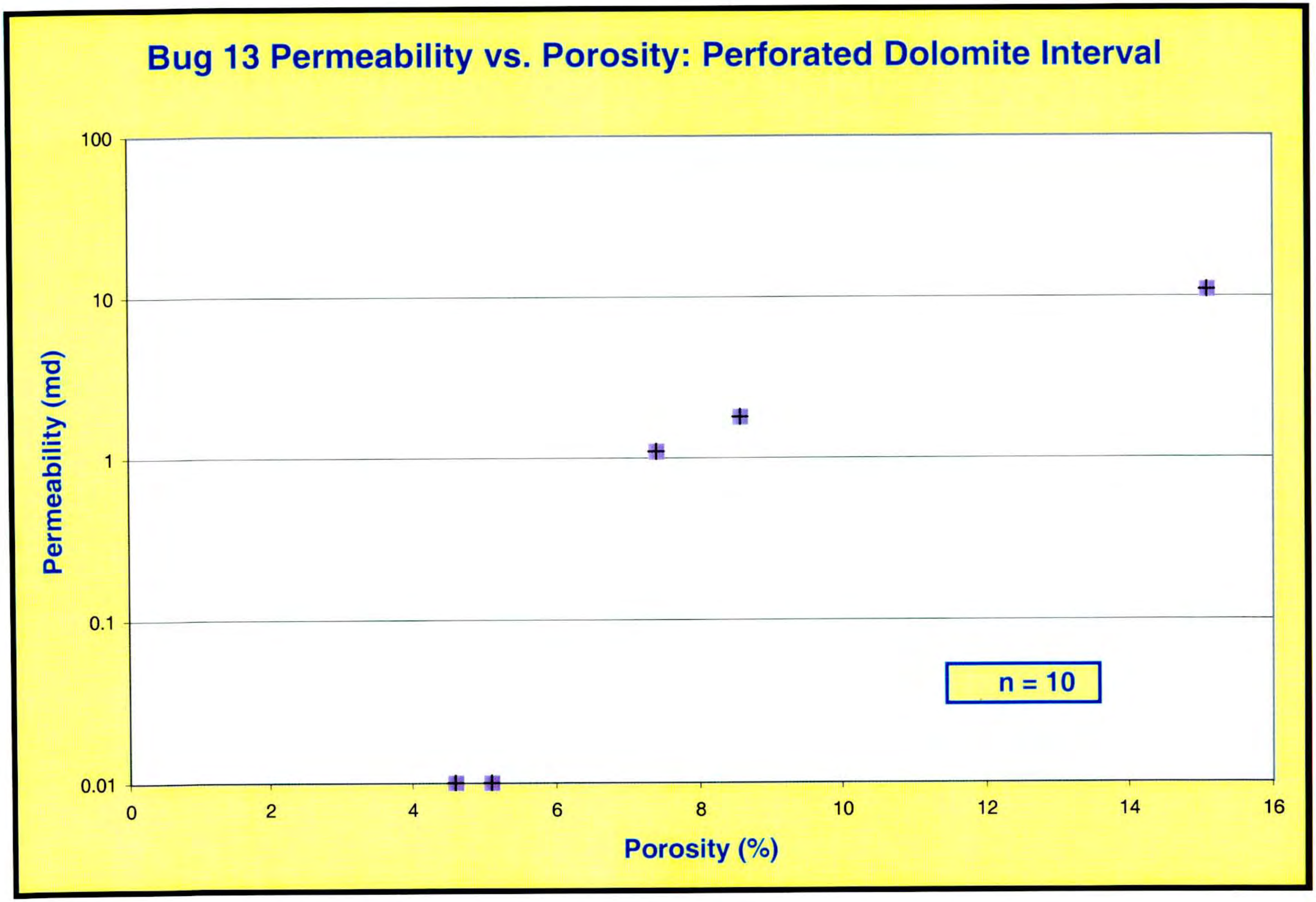
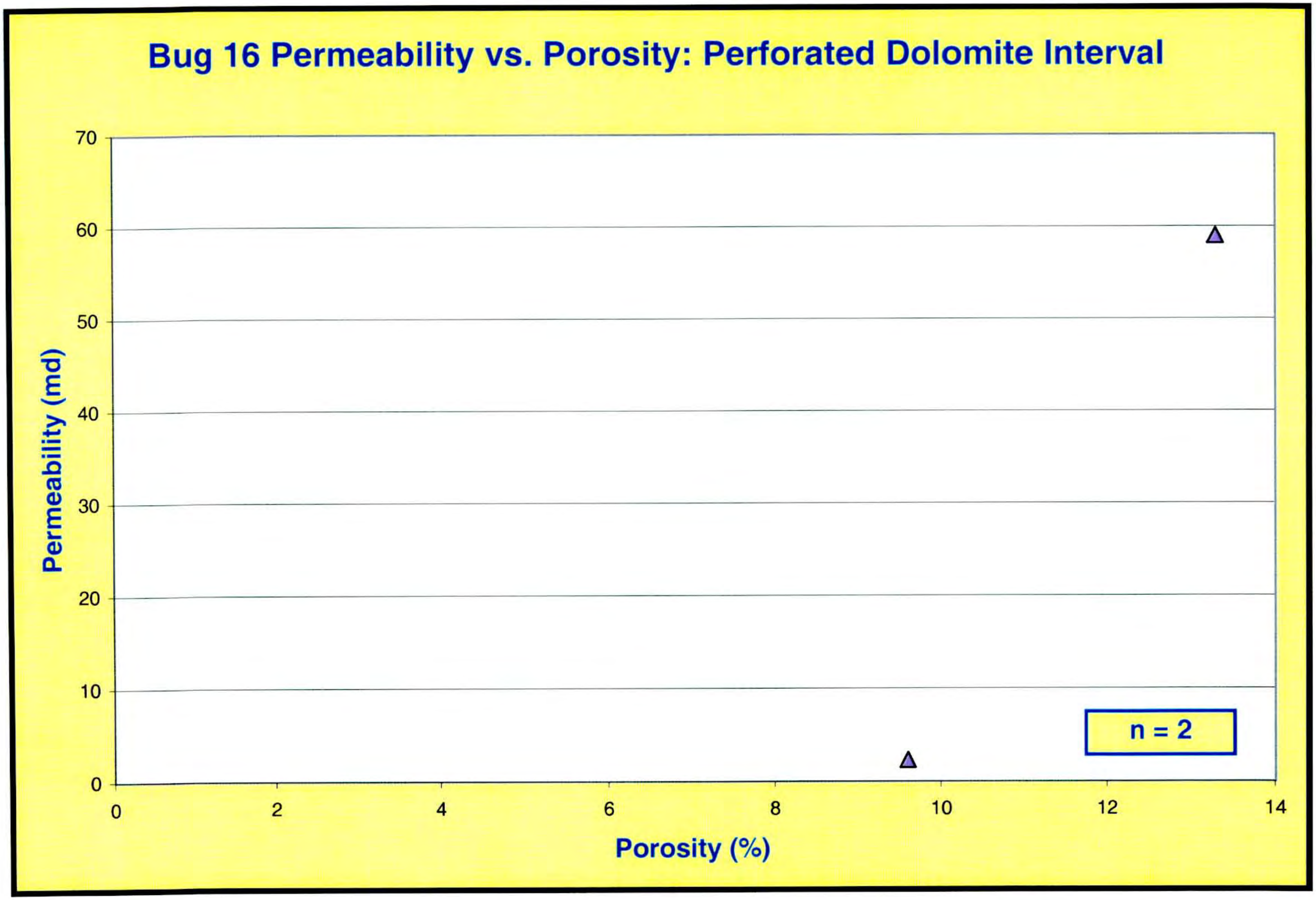
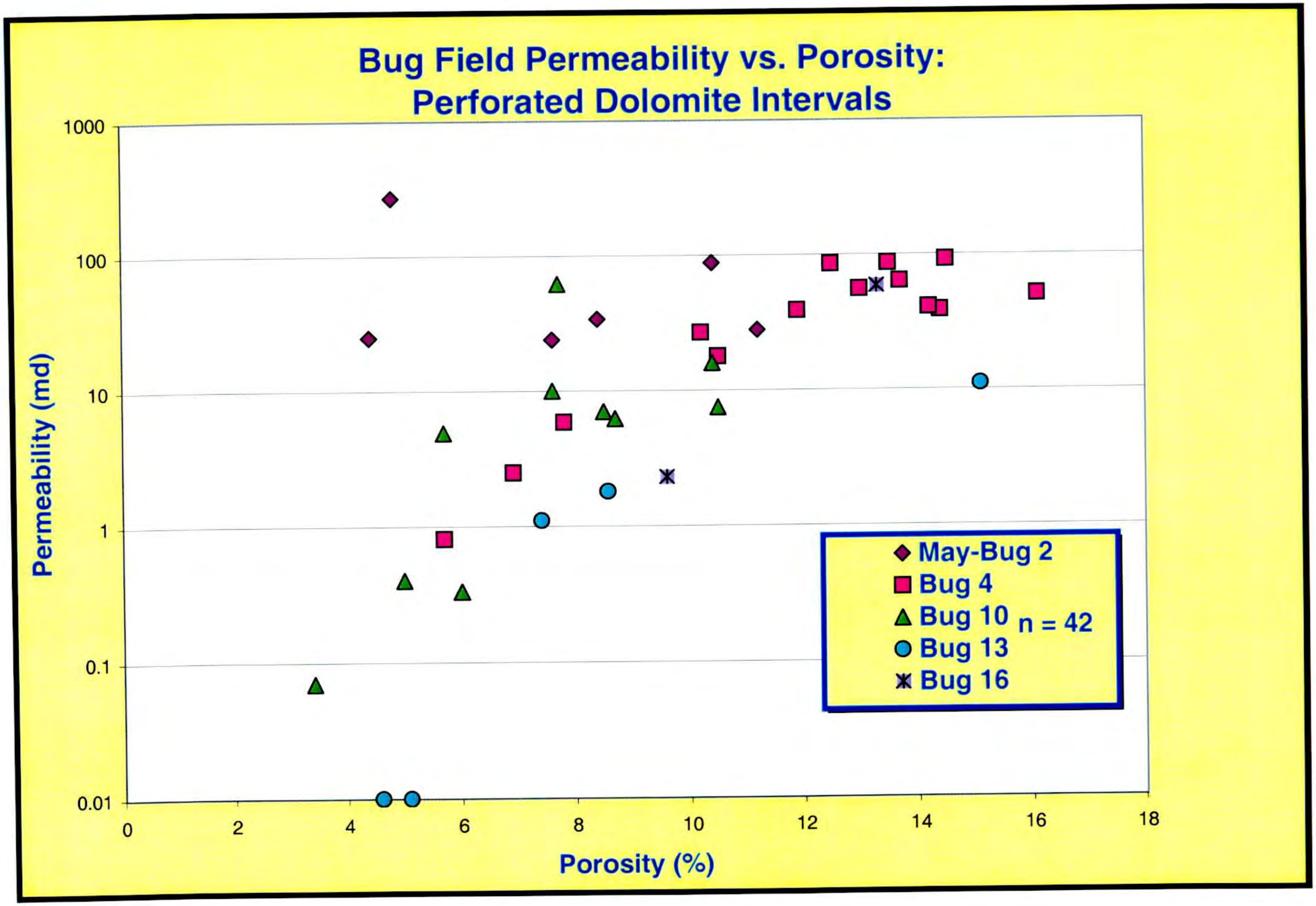

Bug 13 Permeability vs. Porosity: Perforated Dolomite Interval
Permeability (md)
100
10
1
0.1
0.01
0
2
4
6
8
10
12
14
16
Porosity (%)
n = 10

Figure B-23



Bug 16 Permeability vs. Porosity: Perforated Dolomite Interval
Permeability (md)
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
Porosity (%)
n = 2

Figure B-24



Bug Field Permeability vs. Porosity:
Perforated Dolomite Intervals
Permeability (md)
1000
100
10
1
0.1
0.01
0
2
4
6
8
10
12
14
16
18
Porosity (%)
May-Bug 2
Bug 4
Bug 10
Bug 13
Bug 16
n = 42

Figure B-25

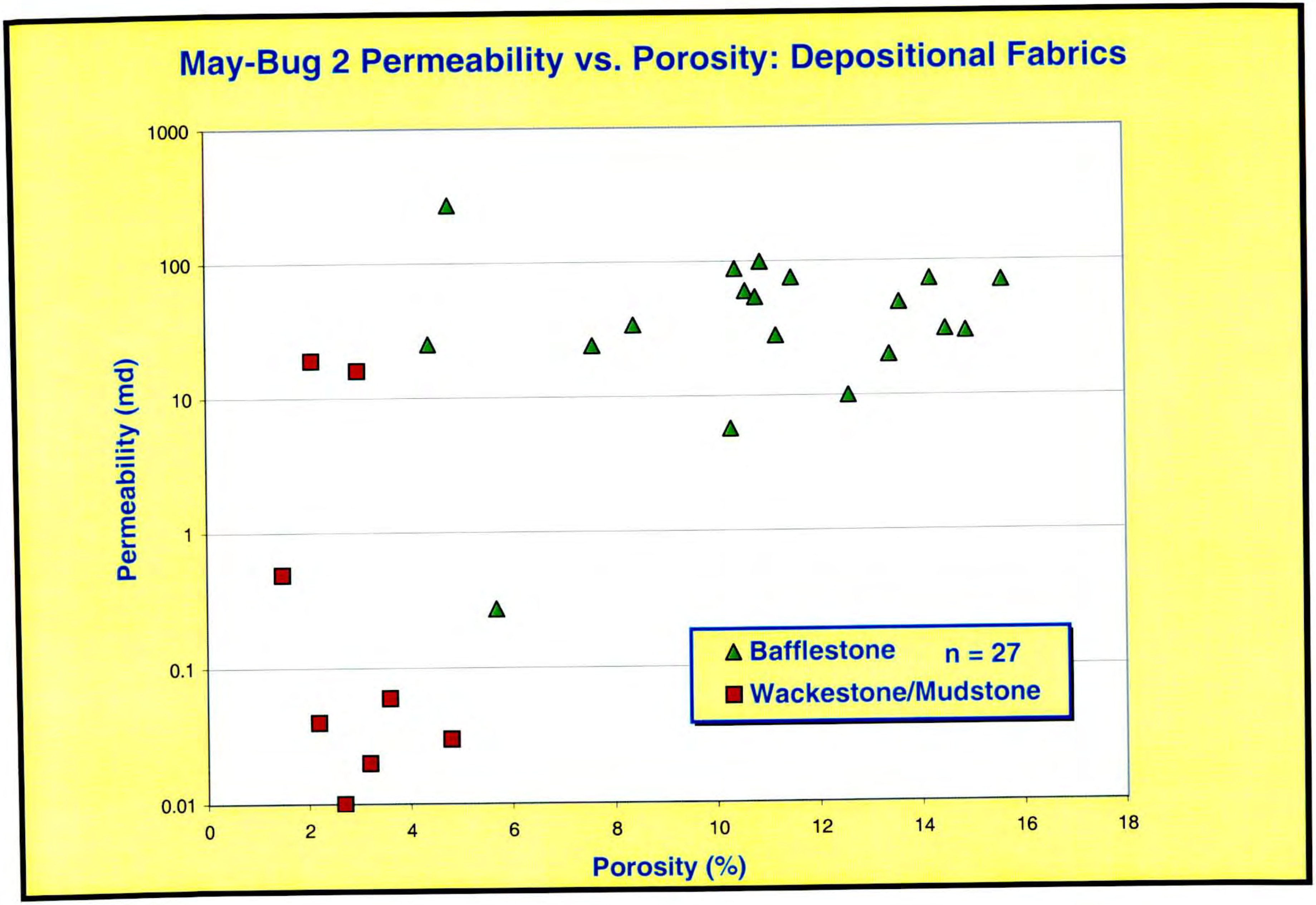

May-Bug 2 Permeability vs. Porosity: Depositional Fabrics
Permeability (md)
1000
100
10
1
0.1
0.01
0
2
4
6
8
10
12
14
16
18
Porosity (%)
Bafflestone
n = 27
Wackestone/Mudstone

Figure B-26

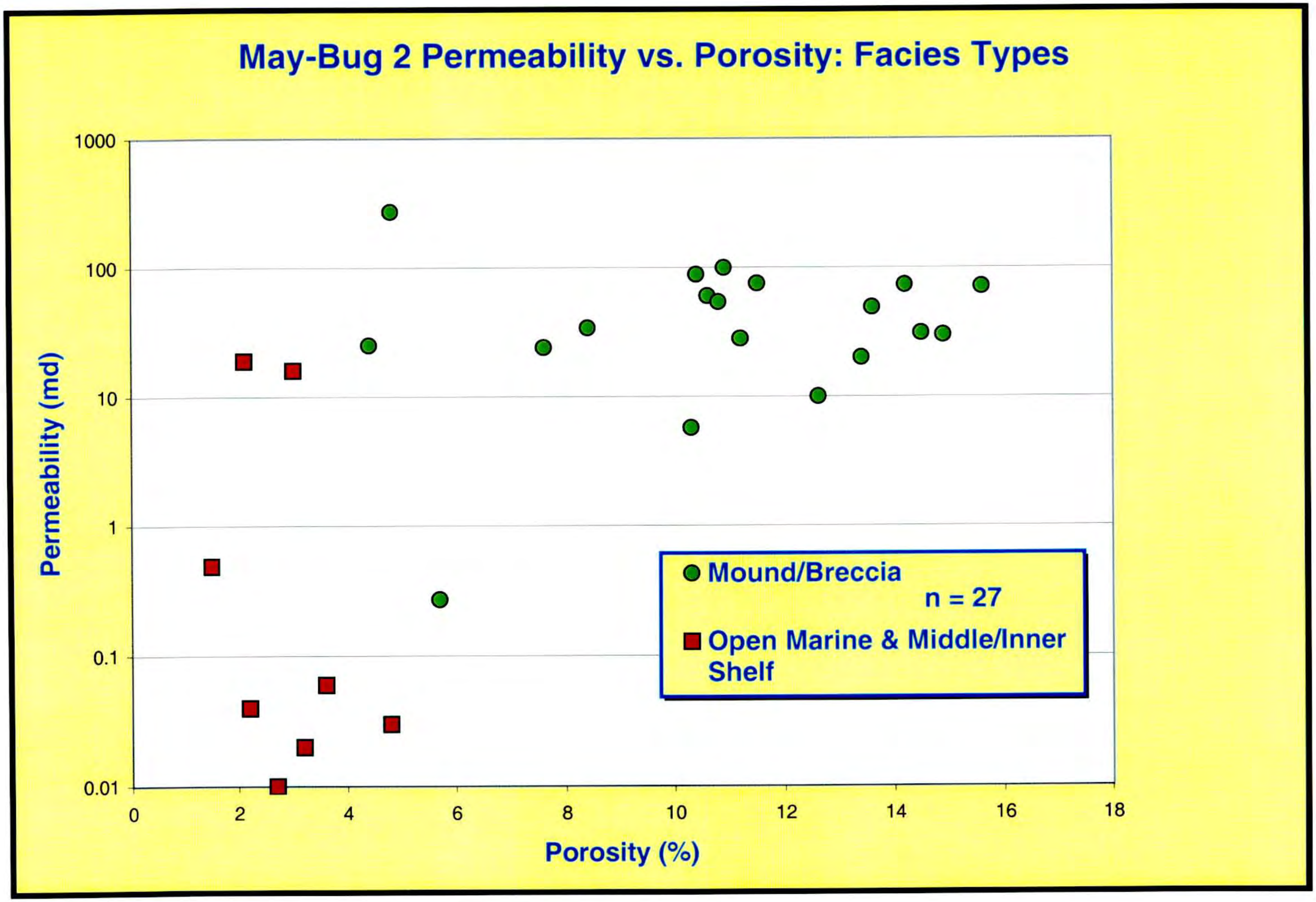

May-Bug 2 Permeability vs. Porosity: Facies Types
Permeability (md)
1000
100
10
1
0.1
0.01
0
2
4
6
8
10
12
14
16
18
Porosity (%)
Mound/Breccia
n = 27
Open Marine & Middle/Inner Shelf

Figure B-27

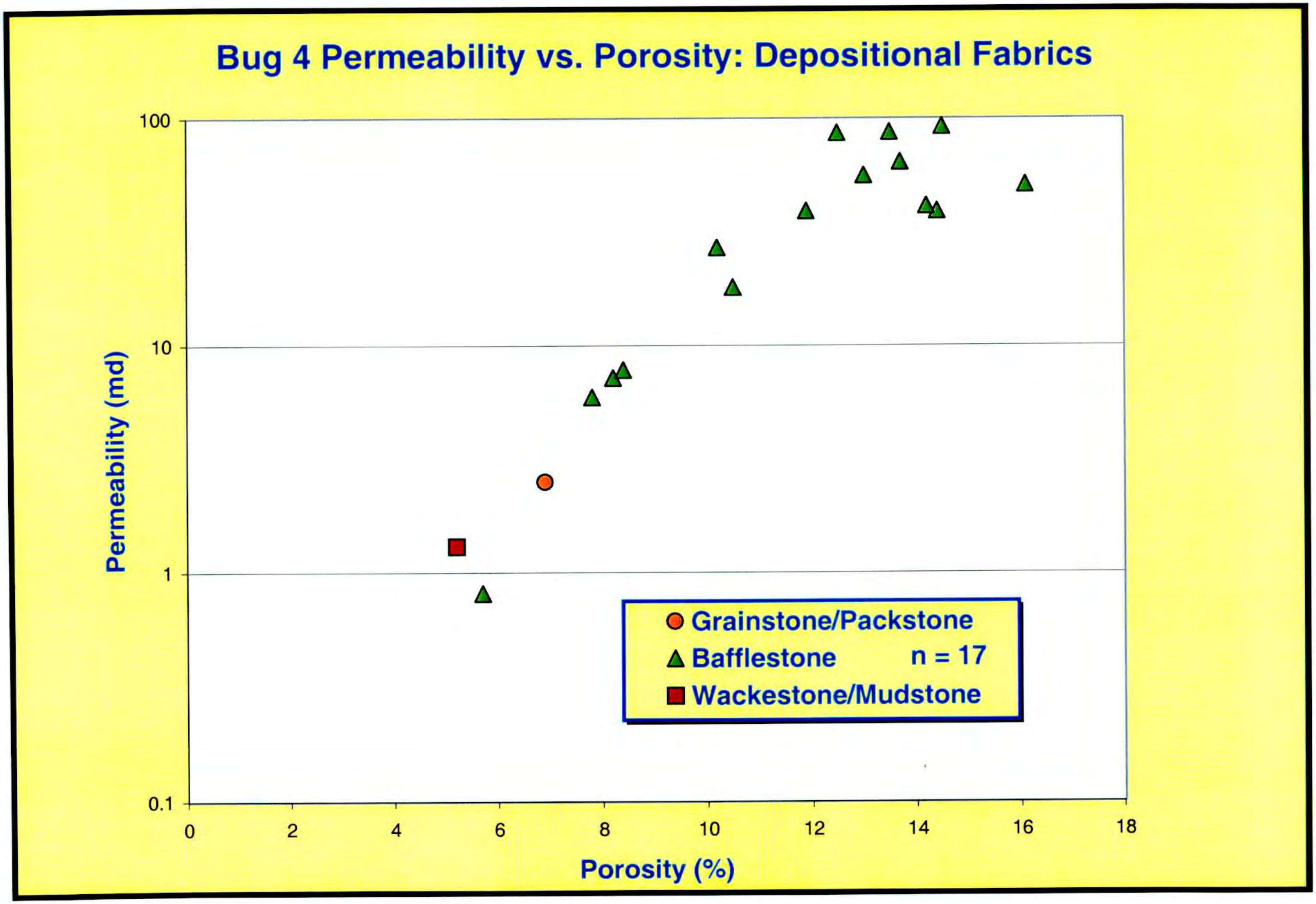
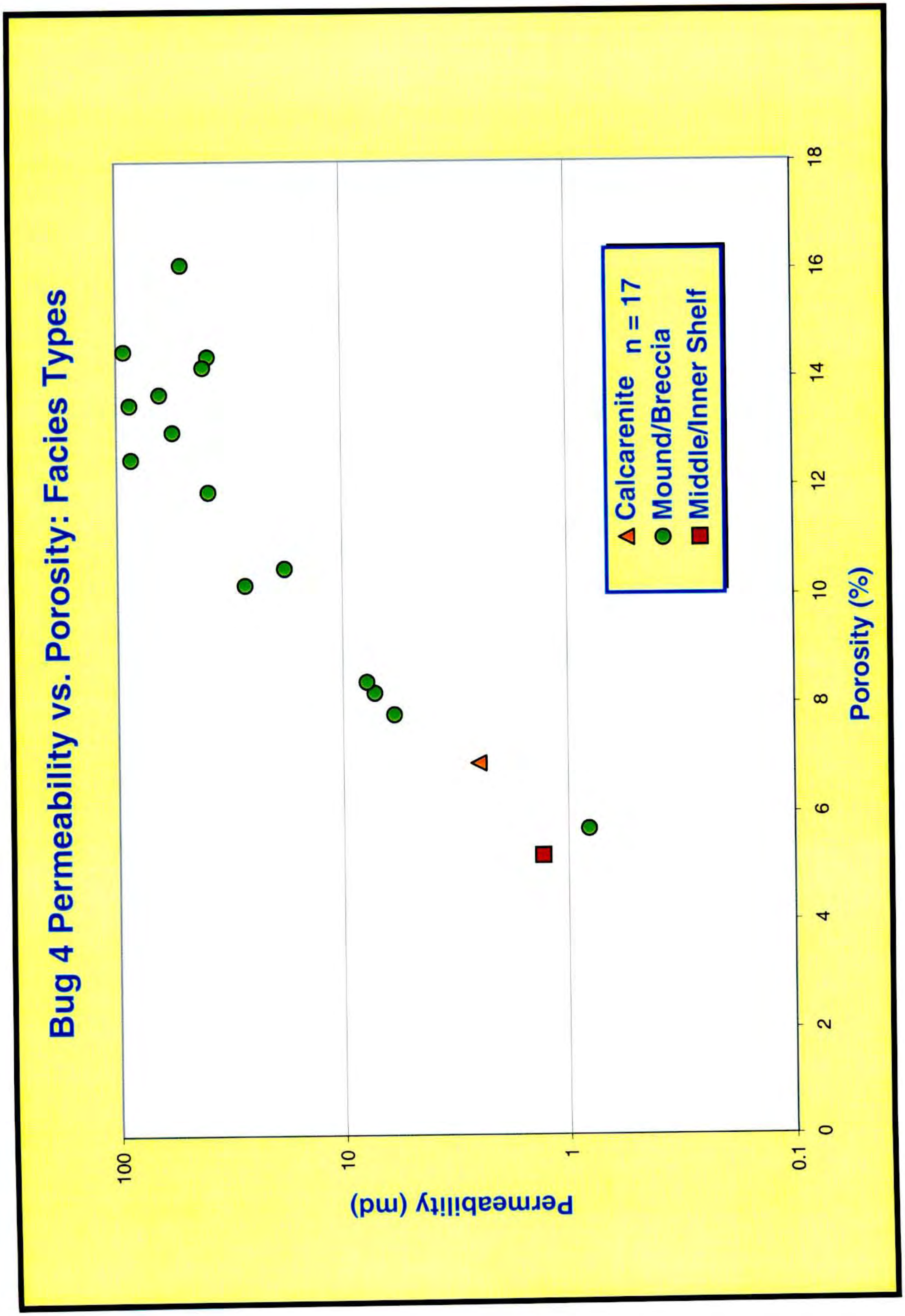

Bug 4 Permeability vs. Porosity: Depositional Fabrics
100
10
1
0.1
Permeability (md)
0
2
4
6
8
10
12
14
16
18
Porosity (%)
Grainstone/Packstone
Bafflestone
n = 17
Wackestone/Mudstone

Figure B-28



Bug 4 Permeability vs. Porosity: Facies Types
Permeability (md)
100
10
1
0.1
0
2
4
6
8
10
12
14
16
18
Porosity (%)
Calcarenite n = 17
Mound/Breccia
Middle/Inner Shelf

Figure B-29

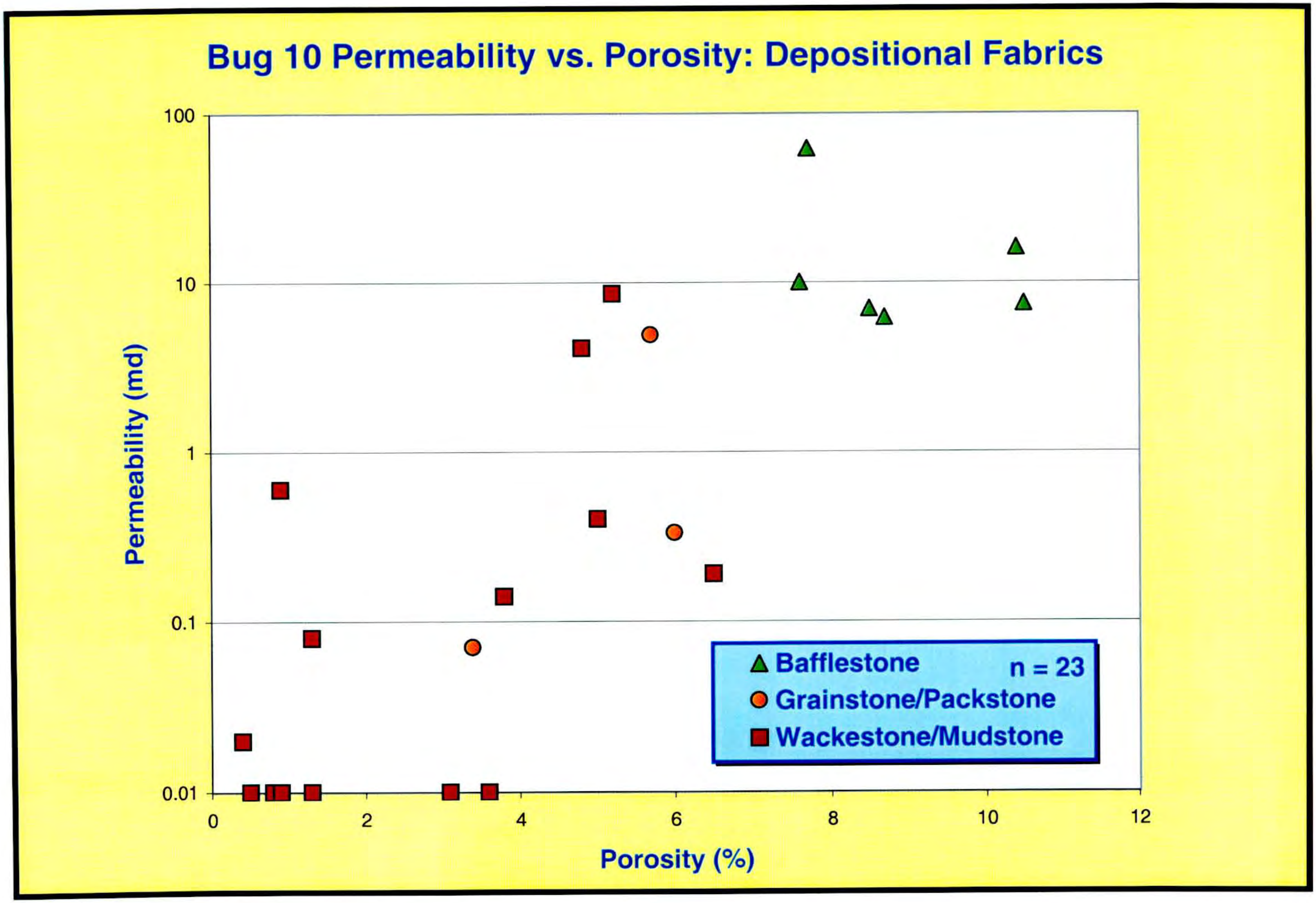

Bug 10 Permeability vs. Porosity: Depositional Fabrics
100
10
1
0.1
0.01
Permeability (md)
0
2
4
6
8
10
12
Porosity (%)
Bafflestone
n = 23
Grainstone/Packstone
Wackestone/Mudstone

Figure B-30

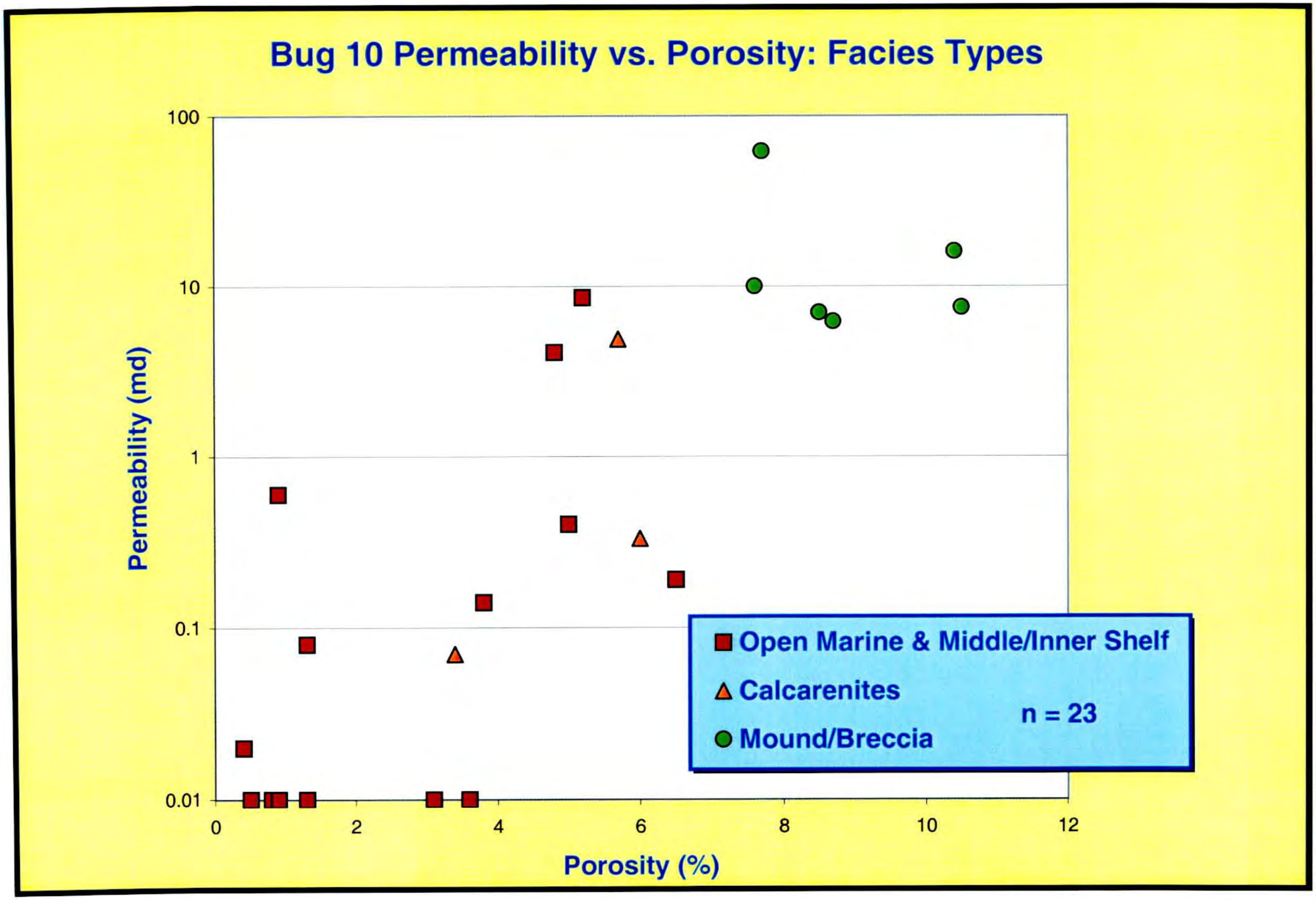
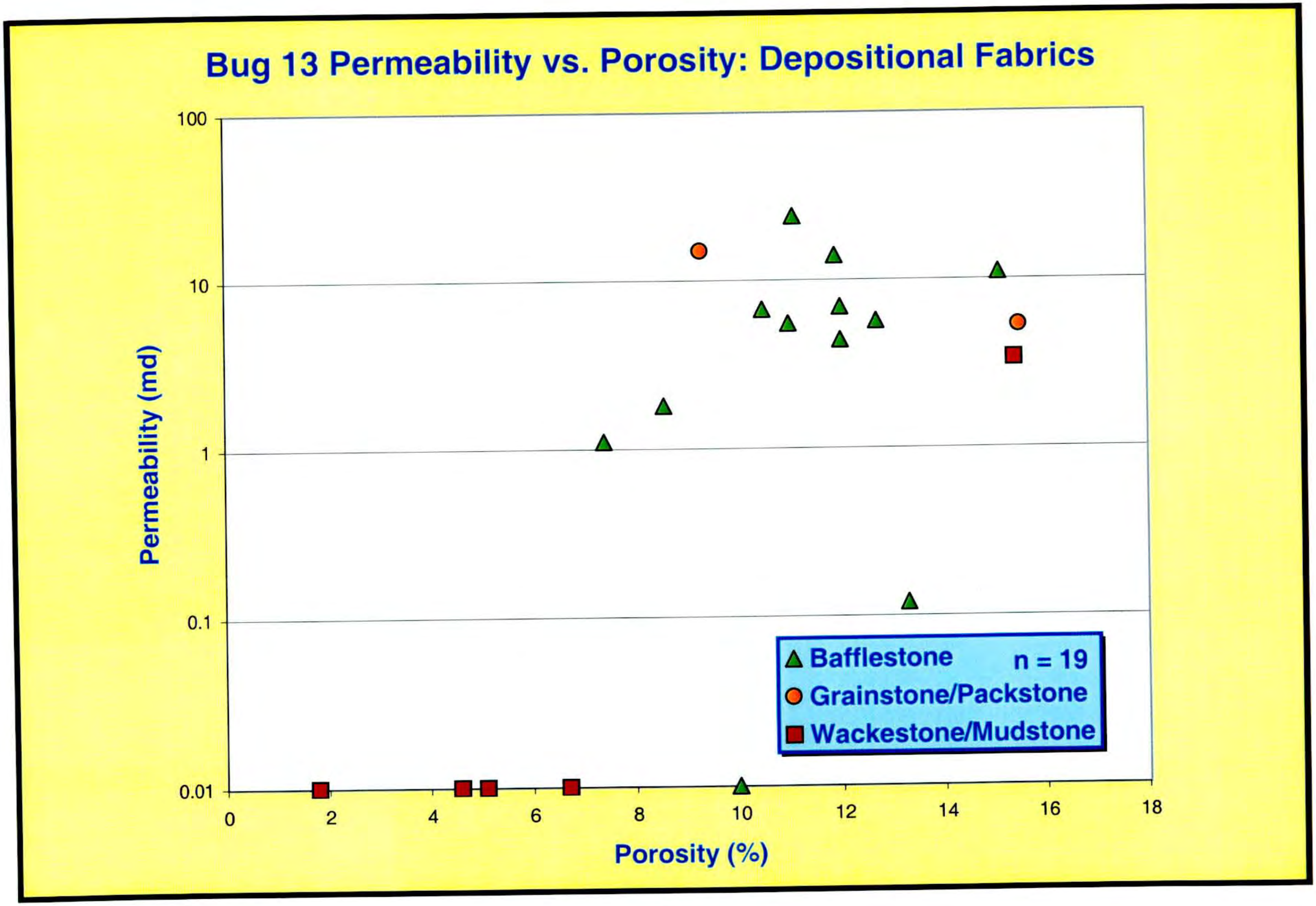
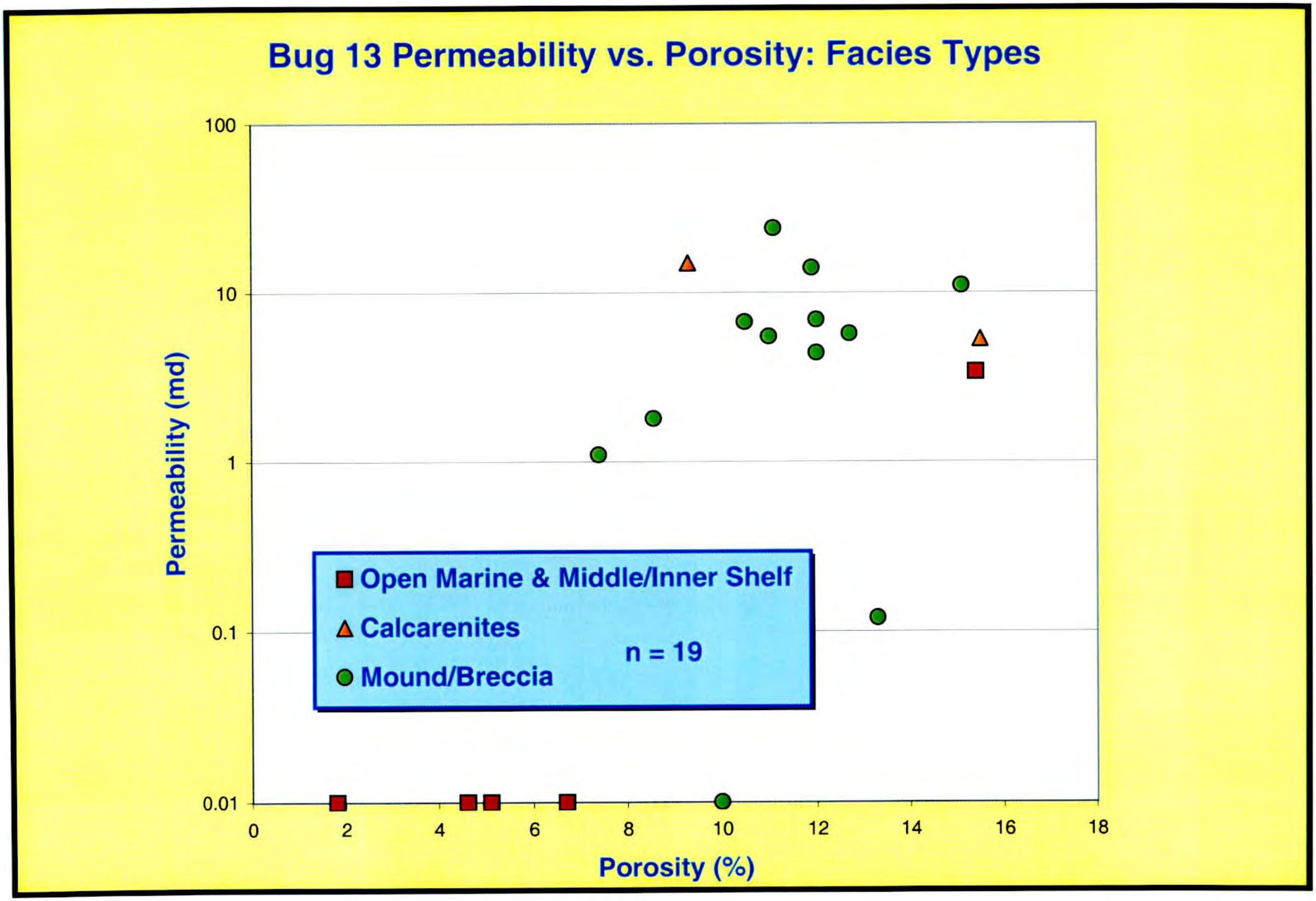

Bug 10 Permeability vs. Porosity: Facies Types
100
10
1
0.1
0.01
Permeability (md)
0
2
4
6
8
10
12
Porosity (%)
Open Marine & Middle/Inner Shelf
Calcarenites
Mound/Breccia
n = 23

Figure B-31



Bug 13 Permeability vs. Porosity: Depositional Fabrics
Permeability (md)
100
10
1
0.1
0.01
0
2
4
6
8
10
12
14
16
18
Porosity (%)
Bafflestone n = 19
Grainstone/Packstone
Wackestone/Mudstone

Figure B-32



Bug 13 Permeability vs. Porosity: Facies Types
100
10
1
0.1
0.01
Permeability (md)
0
2
4
6
8
10
12
14
16
18
Porosity (%)
Open Marine & Middle/Inner Shelf
Calcarenites
Mound/Breccia
n = 19

Figure B-33

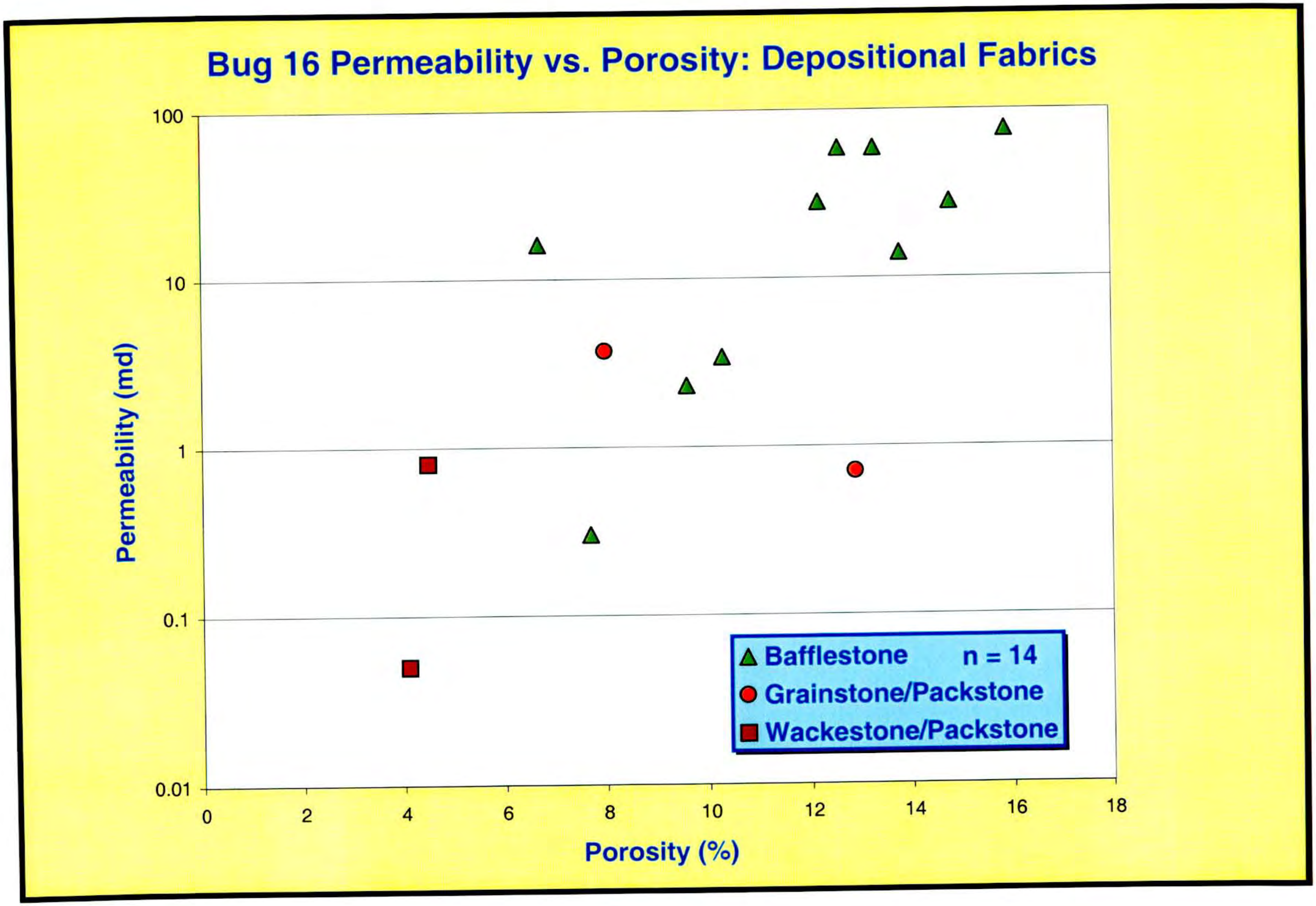

Bug 16 Permeability vs. Porosity: Depositional Fabrics
100
10
1
0.1
0.01
Permeability (md)
0
2
4
6
8
10
12
14
16
18
Porosity (%)
Bafflestone n = 14
Grainstone/Packstone
Wackestone/Packstone

Figure B-34

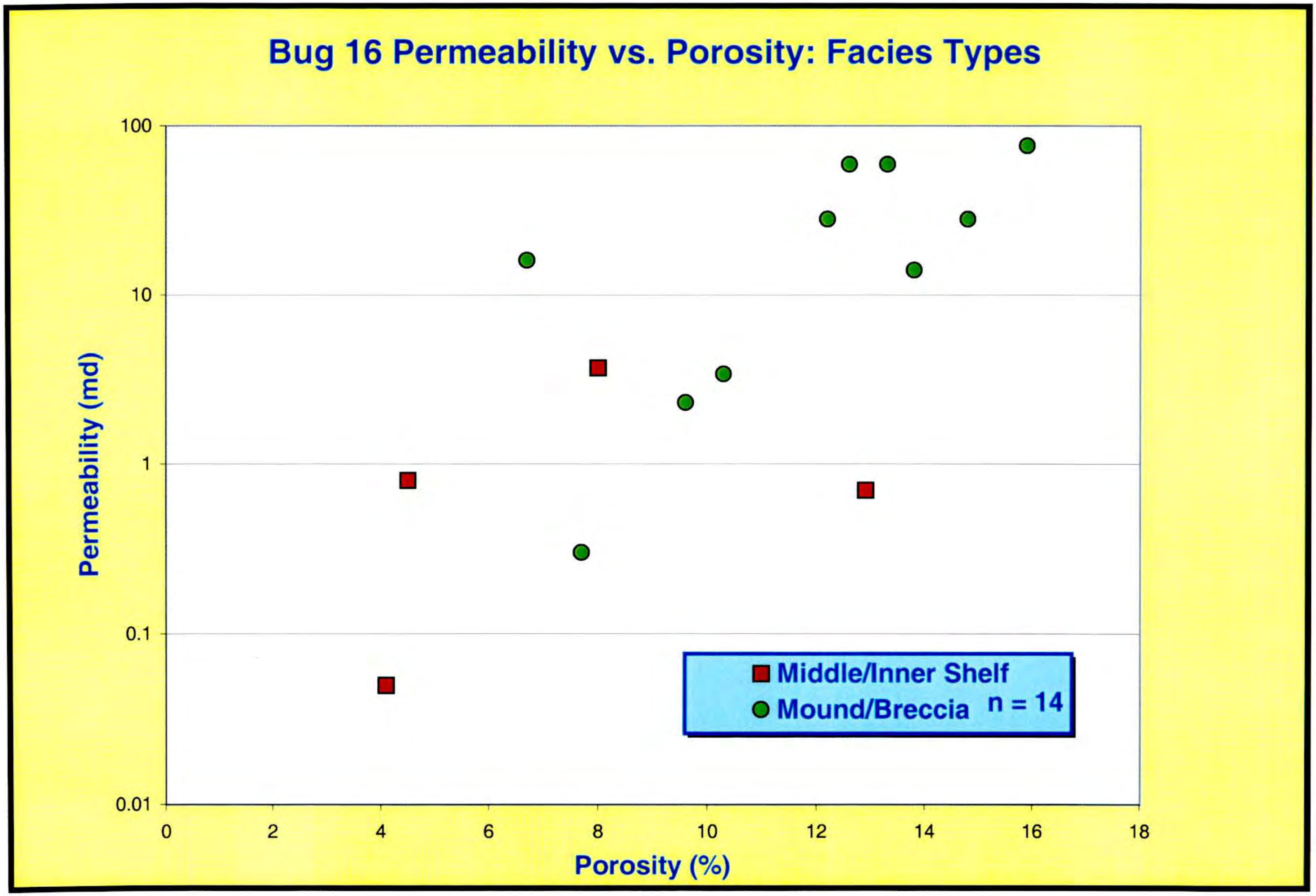

Bug 16 Permeability vs. Porosity: Facies Types
100
10
1
0.1
0.01
Permeability (md)
0
2
4
6
8
10
12
14
16
18
Porosity (%)
Middle/Inner Shelf
Mound/Breccia
n = 14

Figure B-35

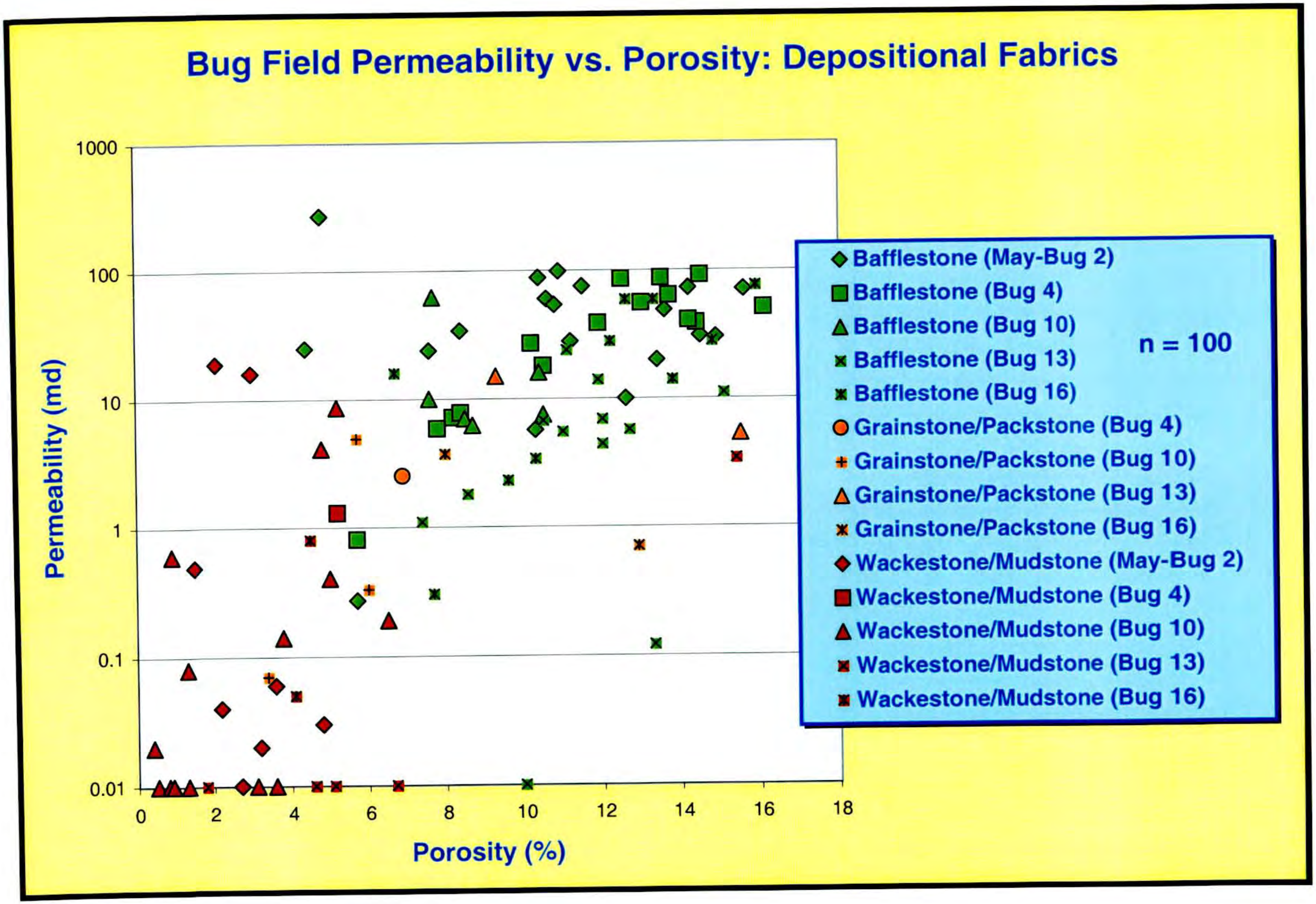

Bug Field Permeability vs. Porosity: Depositional Fabrics
Permeability (md)
1000
100
10
1
0.1
0.01
0
2
4
6
8
10
12
14
16
18
Porosity (%)
Bafflestone (May-Bug 2)
Bafflestone (Bug 4)
Bafflestone (Bug 10)
Bafflestone (Bug 13)
Bafflestone (Bug 16)
Grainstone/Packstone (Bug 4)
Grainstone/Packstone (Bug 10)
Grainstone/Packstone (Bug 13)
Grainstone/Packstone (Bug 16)
Wackestone/Mudstone (May-Bug 2)
Wackestone/Mudstone (Bug 4)
Wackestone/Mudstone (Bug 10)
Wackestone/Mudstone (Bug 13)
Wackestone/Mudstone (Bug 16)
n = 100

Figure B-36

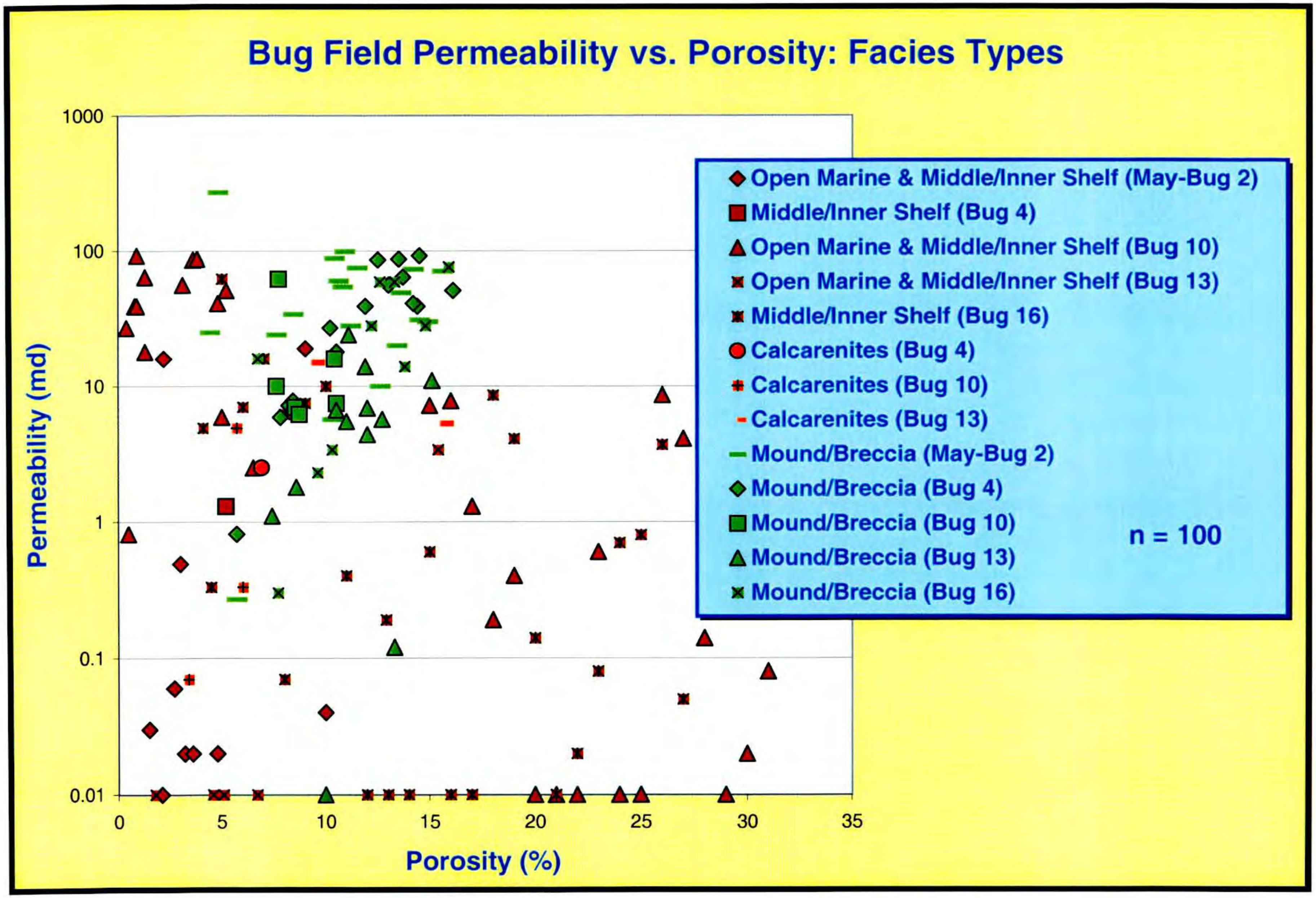

Bug Field Permeability vs. Porosity: Facies Types
Permeability (md)
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
35
Porosity (%)
Open Marine & Middle/Inner Shelf (May-Bug 2)
Middle/Inner Shelf (Bug 4)
Open Marine & Middle/Inner Shelf (Bug 10)
Open Marine & Middle/Inner Shelf (Bug 13)
Middle/Inner Shelf (Bug 16)
Calcarenites (Bug 4)
Calcarenites (Bug 10)
Calcarenites (Bug 13)
Mound/Breccia (May-Bug 2)
Mound/Breccia (Bug 4)
Mound/Breccia (Bug 10)
Mound/Breccia (Bug 13)
Mound/Breccia (Bug 16)
n = 100

Figure B-37

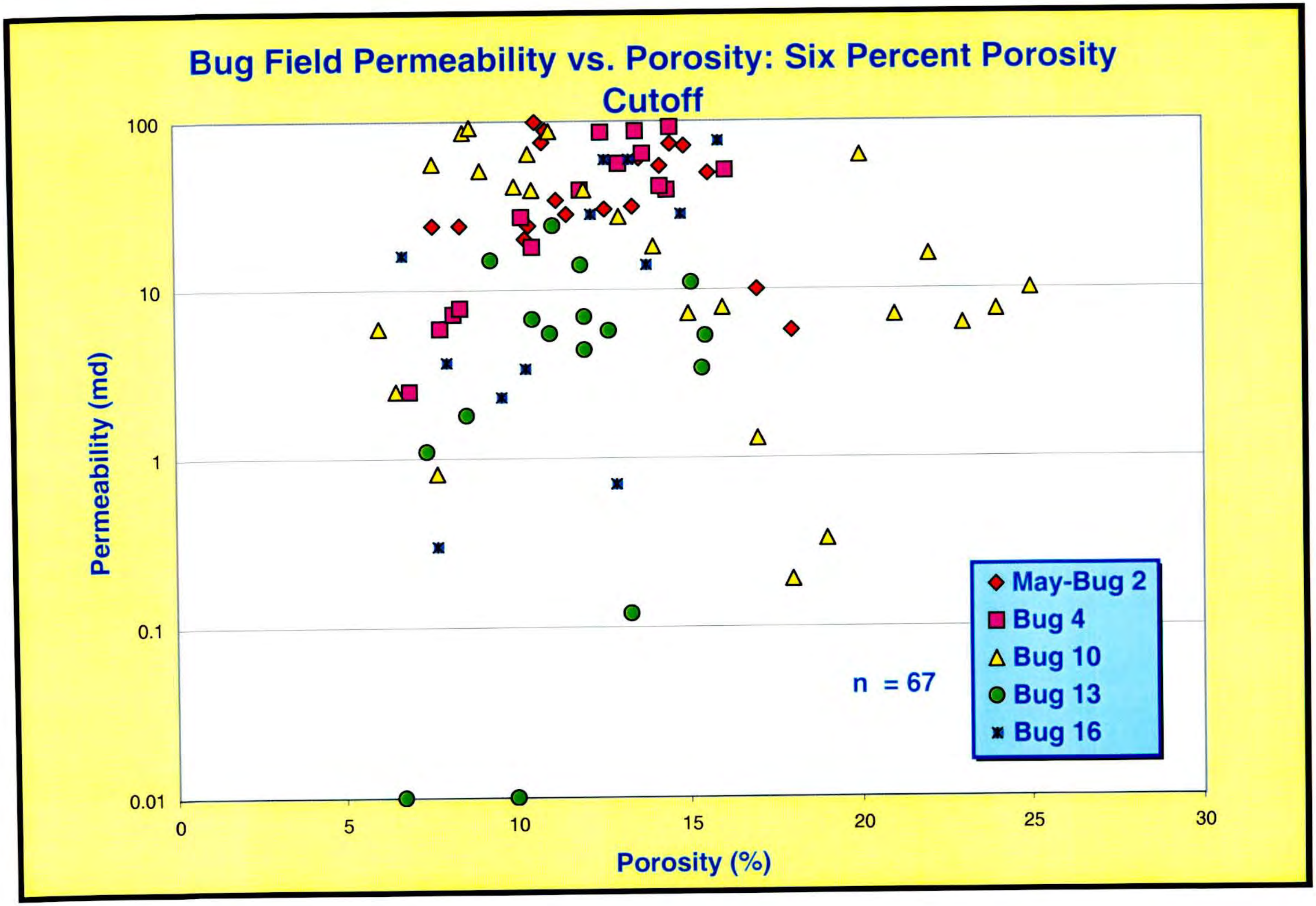

Bug Field Permeability vs. Porosity: Six Percent Porosity Cutoff
Permeability (md)
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)
n = 67
May-Bug 2
Bug 4
Bug 10
Bug 13
Bug 16

Figure B-38

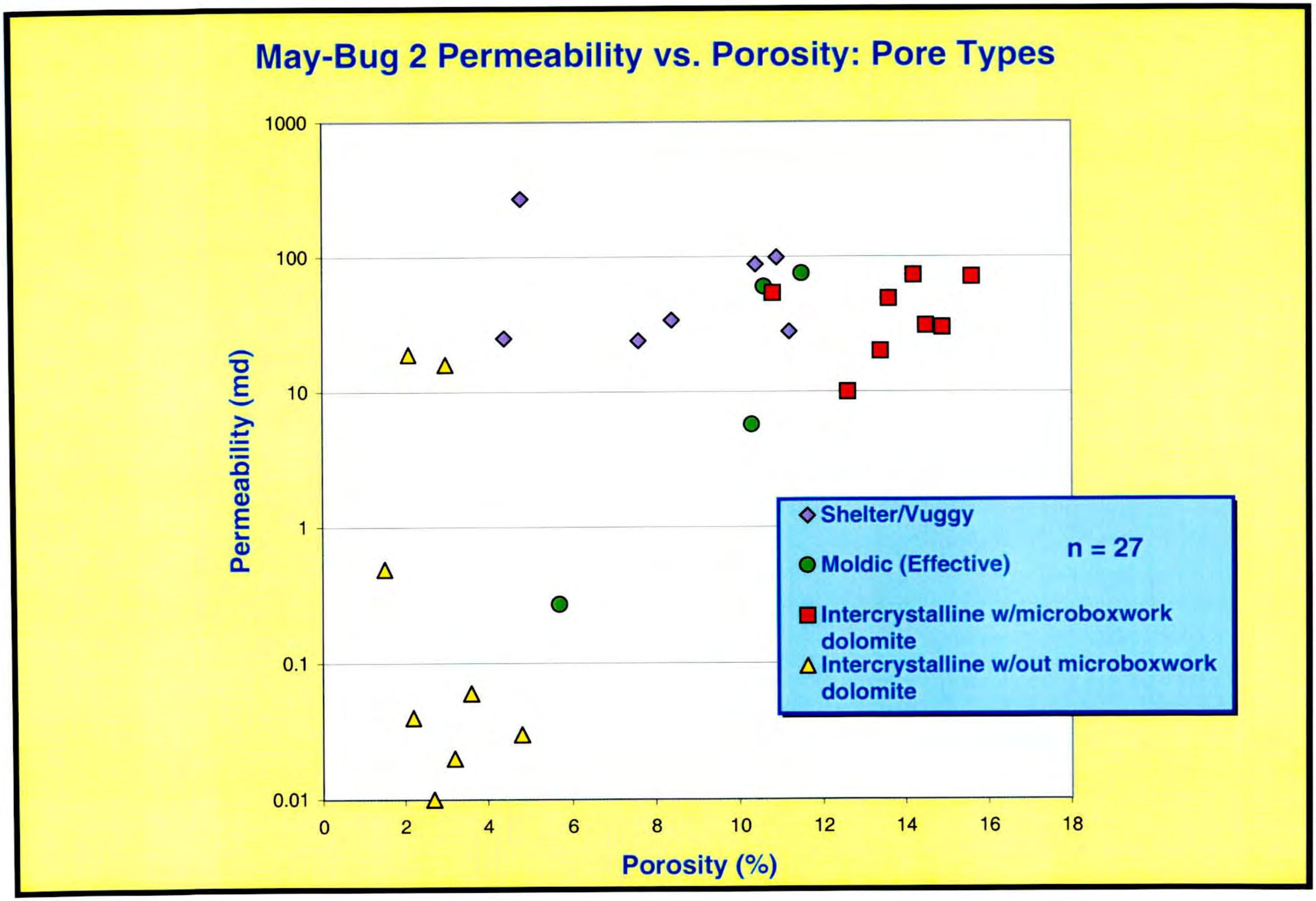
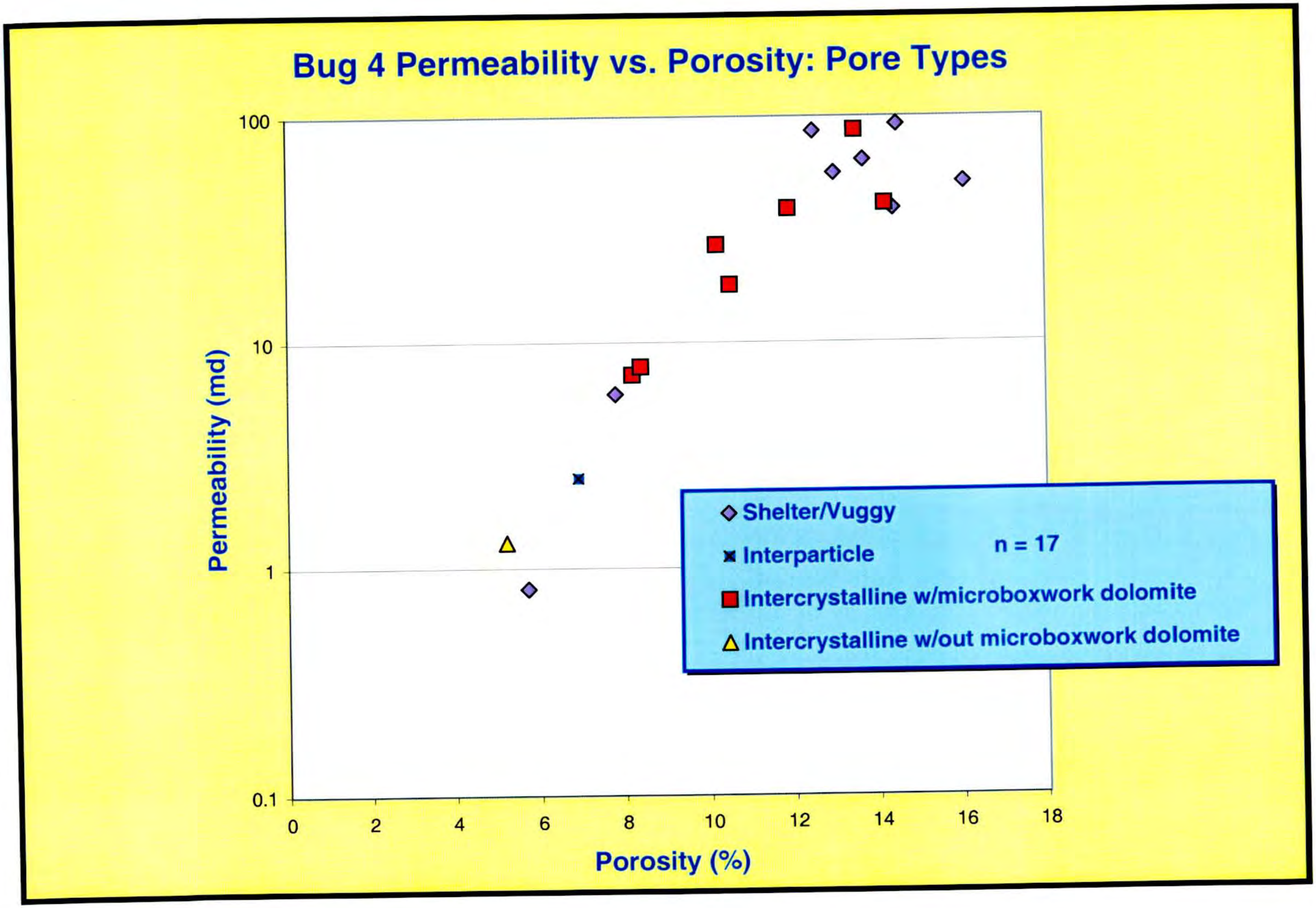

May-Bug 2 Permeability vs. Porosity: Pore Types
Permeability (md)
1000
100
10
1
0.1
0.01
0
2
4
6
8
10
12
14
16
18
Porosity (%)
Shelter/Vuggy
Moldic (Effective)
n = 27
Intercrystalline w/microboxwork dolomite
Intercrystalline w/out microboxwork dolomite

Figure B-39



Bug 4 Permeability vs. Porosity: Pore Types
Permeability (md)
100
10
1
0.1
0
2
4
6
8
10
12
14
16
18
Porosity (%)
Shelter/Vuggy
Interparticle
n = 17
Intercrystalline w/microboxwork dolomite
Intercrystalline w/out microboxwork dolomite

Figure B-40

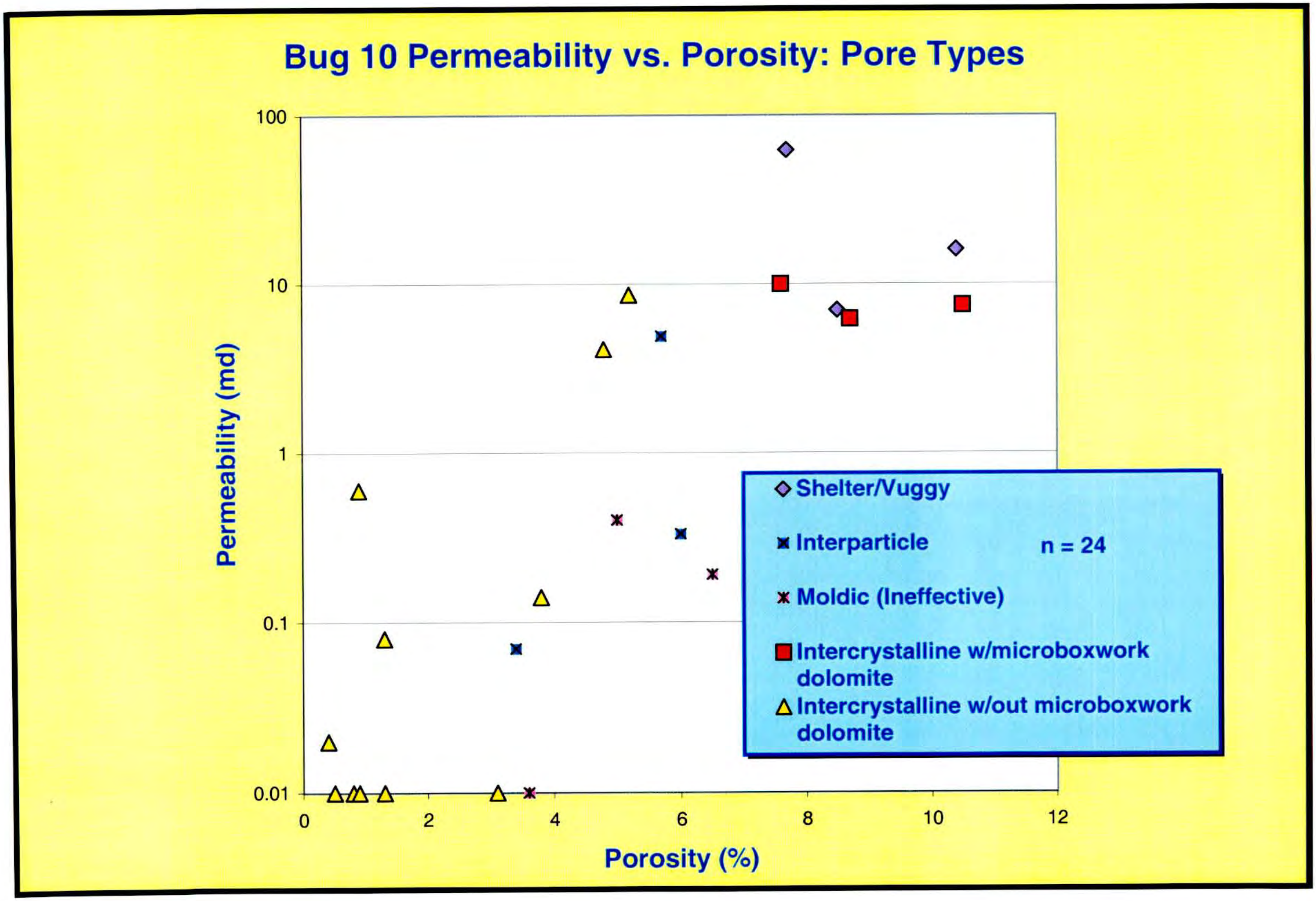
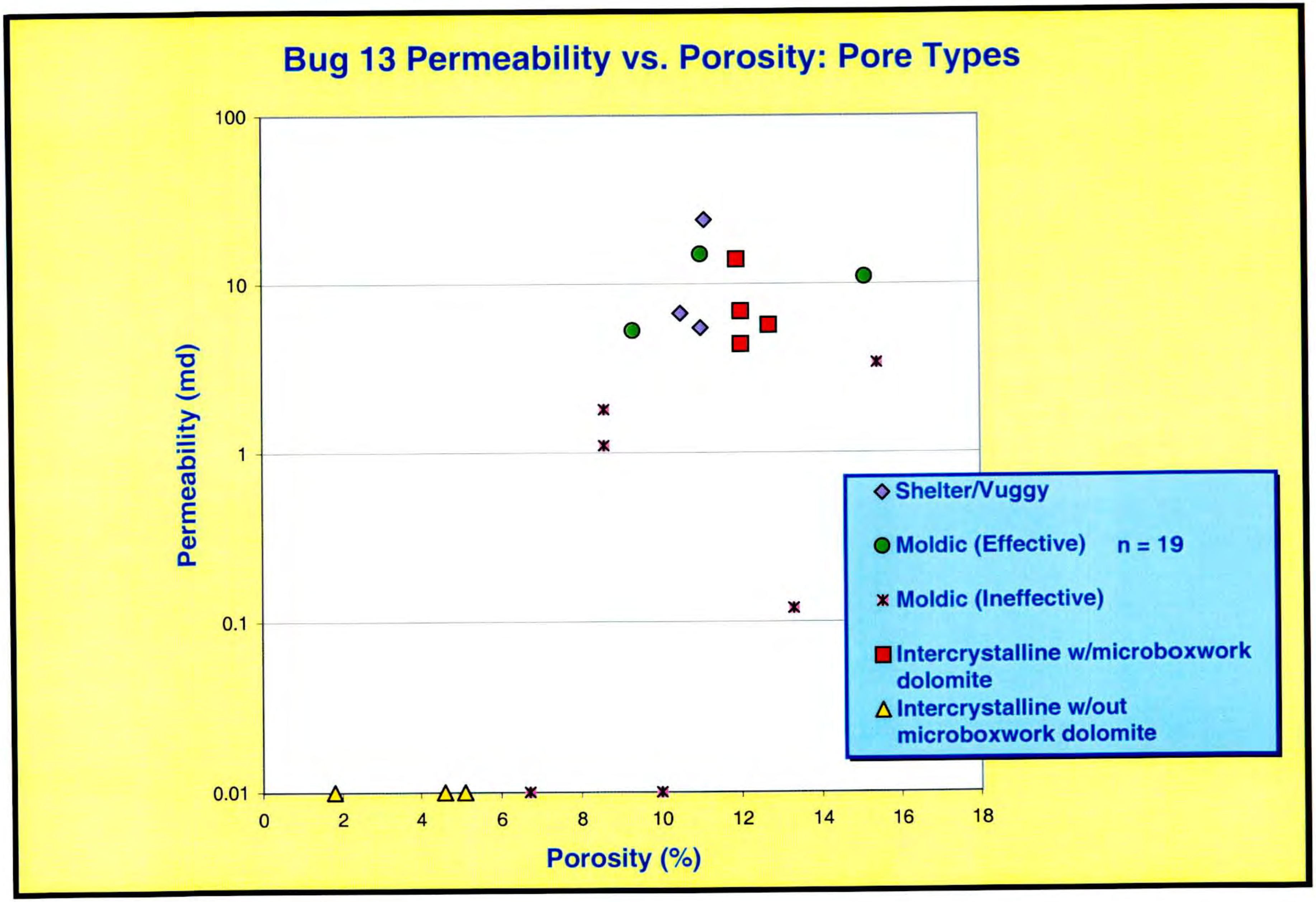

Bug 10 Permeability vs. Porosity: Pore Types
100
10
1
0.1
0.01
Permeability (md)
0
2
4
6
8
10
12
Porosity (%)
Shelter/Vuggy
Interparticle
n = 24
Moldic (Ineffective)
Intercrystalline w/microboxwork dolomite
Intercrystalline w/out microboxwork dolomite

Figure B-41



Bug 13 Permeability vs. Porosity: Pore Types
Permeability (md)
100
10
1
0.1
0.01
0
2
4
6
8
10
12
14
16
18
Porosity (%)
Shelter/Vuggy
Moldic (Effective)
n = 19
Moldic (Ineffective)
Intercrystalline w/microboxwork dolomite
Intercrystalline w/out microboxwork dolomite

Figure B-42

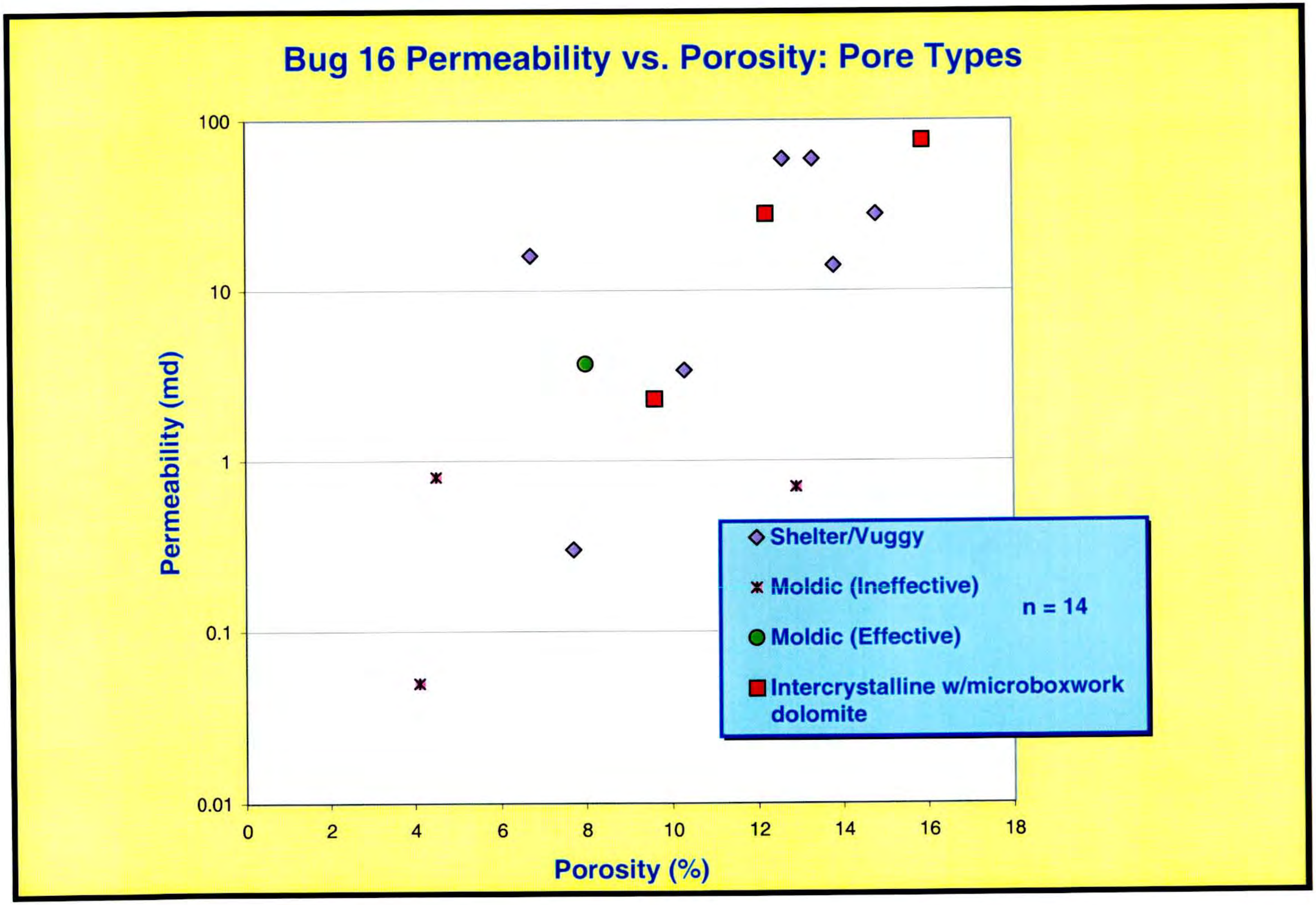
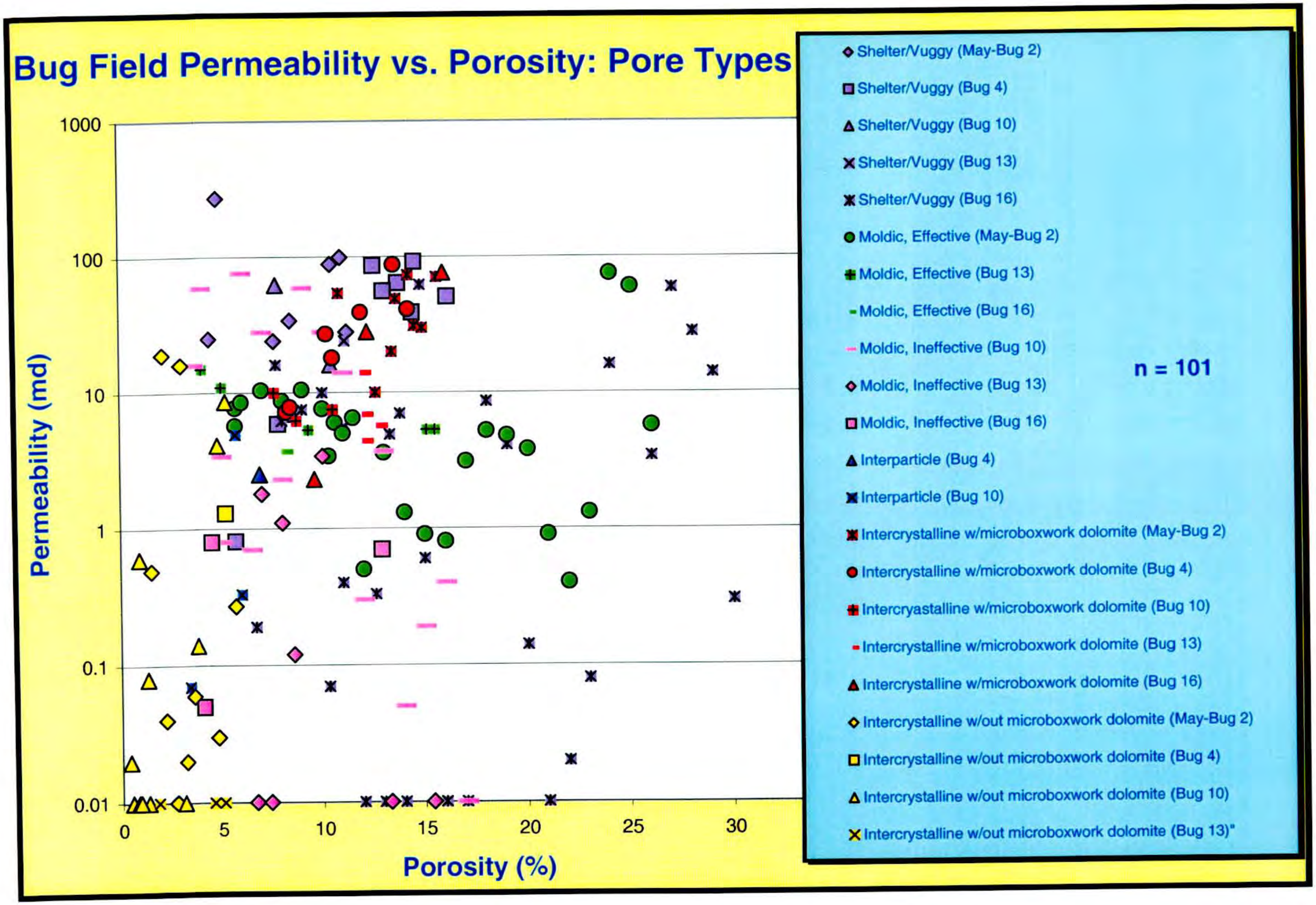

Bug 16 Permeability vs. Porosity: Pore Types
Permeability (md)
100
10
1
0.1
0.01
0
2
4
6
8
10
12
14
16
18
Porosity (%)
Shelter/Vuggy
Moldic (Ineffective)
Moldic (Effective)
Intercrystalline w/microboxwork dolomite
n = 14

Figure B-43



Bug Field Permeability vs. Porosity: Pore Types
Permeability (md)
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)
Shelter/Vuggy (May-Bug 2)
Shelter/Vuggy (Bug 4)
Shelter/Vuggy (Bug 10)
Shelter/Vuggy (Bug 13)
Shelter/Vuggy (Bug 16)
Moldic, Effective (May-Bug 2)
Moldic, Effective (Bug 13)
Moldic, Effective (Bug 16)
Moldic, Ineffective (Bug 10)
Moldic, Ineffective (Bug 13)
Moldic, Ineffective (Bug 16)
Interparticle (Bug 4)
Interparticle (Bug 10)
Intercrystalline w/microboxwork dolomite (May-Bug 2)
Intercrystalline w/microboxwork dolomite (Bug 4)
Intercryastalline w/microboxwork dolomite (Bug 10)
Intercrystalline w/microboxwork dolomite (Bug 13)
Intercrystalline w/microboxwork dolomite (Bug 16)
Intercrystalline w/out microboxwork dolomite (May-Bug 2)
Intercrystalline w/out microboxwork dolomite (Bug 4)
Intercrystalline w/out microboxwork dolomite (Bug 10)
Intercrystalline w/out microboxwork dolomite (Bug 13)"
n = 101

Figure B-44