IOWA STATE UNIVERSITY

Institute for Transportation

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Carbonate Aggregate in Concrete

Research Progress,

Reported by

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Acknowledgement

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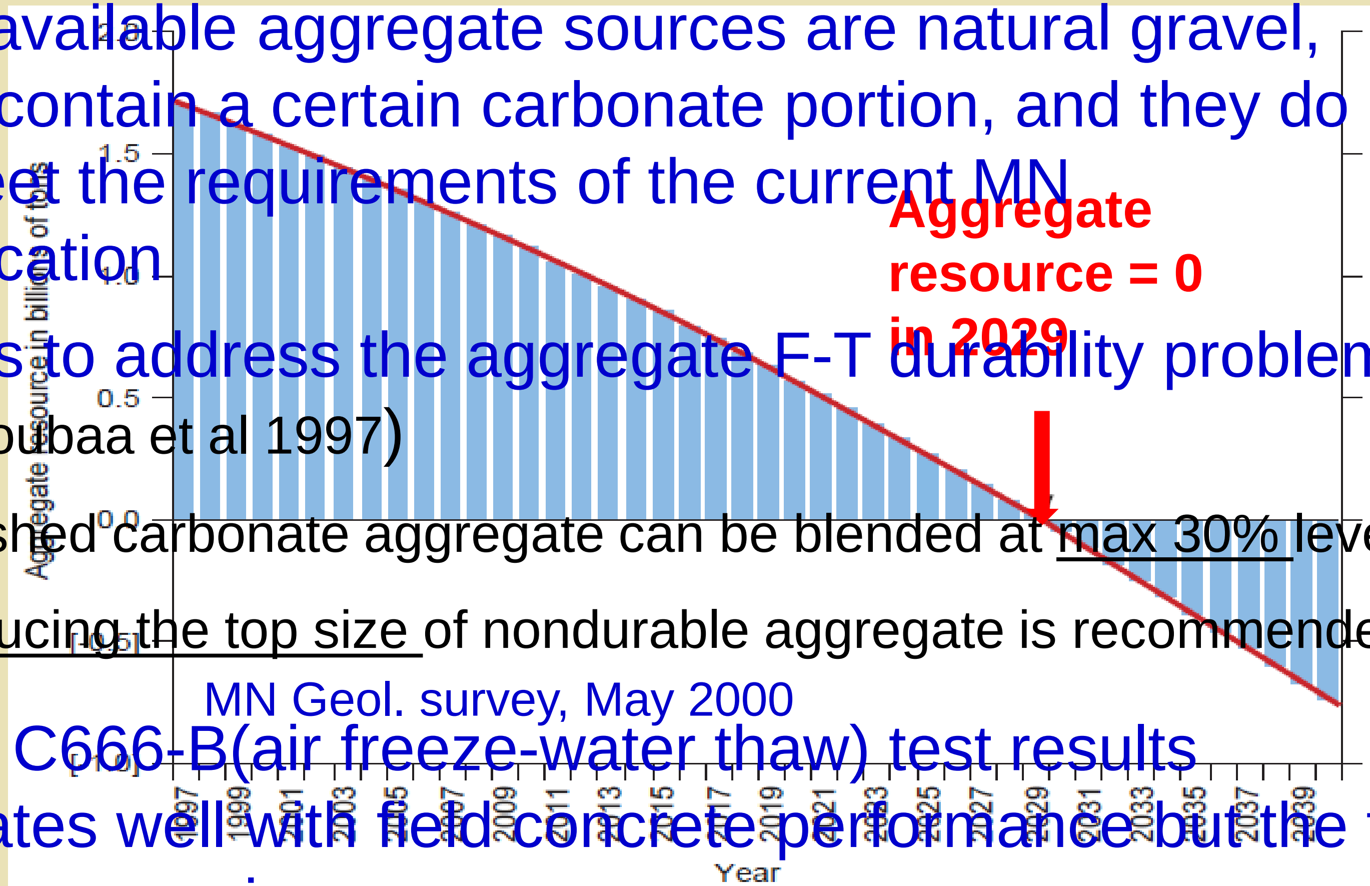
Background

- Minnesota aggregate supplies are diminishing.
- Many available aggregate sources are natural gravel, which contain a certain carbonate portion, and they do not meet the requirements of the current MN specification
- Studies to address the aggregate F-T durability problems in MN (Koubaa et al 1997)
  - Crushed carbonate aggregate can be blended at max 30% level
  - Reducing the top size of nondurable aggregate is recommended



MN Geol. survey, May 2000

- ASTM C666-B(air freeze-water thaw) test results correlates well with field concrete performance but the test is time consuming

Current Specification

DIVISION III
MATERIALS
3137

Coarse Aggregate for Portland Cement Concrete

D3 Aggregate for Concrete Paving

For use in any part of a concrete pavement, quality requirements for the coarse aggregate shall be as prescribed in 3137.2D1 above, except as modified or supplemented by the following maximum percentages:

All fractions of the coarse aggregate for concrete pavement shall meet one of the following requirements:

(a) Class A aggregate
(b) Class B aggregate with a maximum absorption.................1.75%
(c) Class C aggregate with a maximum carbonate
by mass (**weight**)...30%

B1 Class A

Class A aggregate shall consist of crushed quarry or mine trap rock (basalt, diabase, gabbro or other related igneous rock types), quartzite, gneiss or granite. Other igneous or metamorphic quarry or mine rock may be used only with specific approval of the Engineer. Crushed aggregate produced from igneous or quartzite stones retained on a 100 mm (**4 inch**) screen will also be permitted by approval of the Engineer.

B2 Class B

Class B aggregate shall consist of all other crushed quarry or mine rock; i.e., carbonates, rhyolite, schist.

B3 Class C

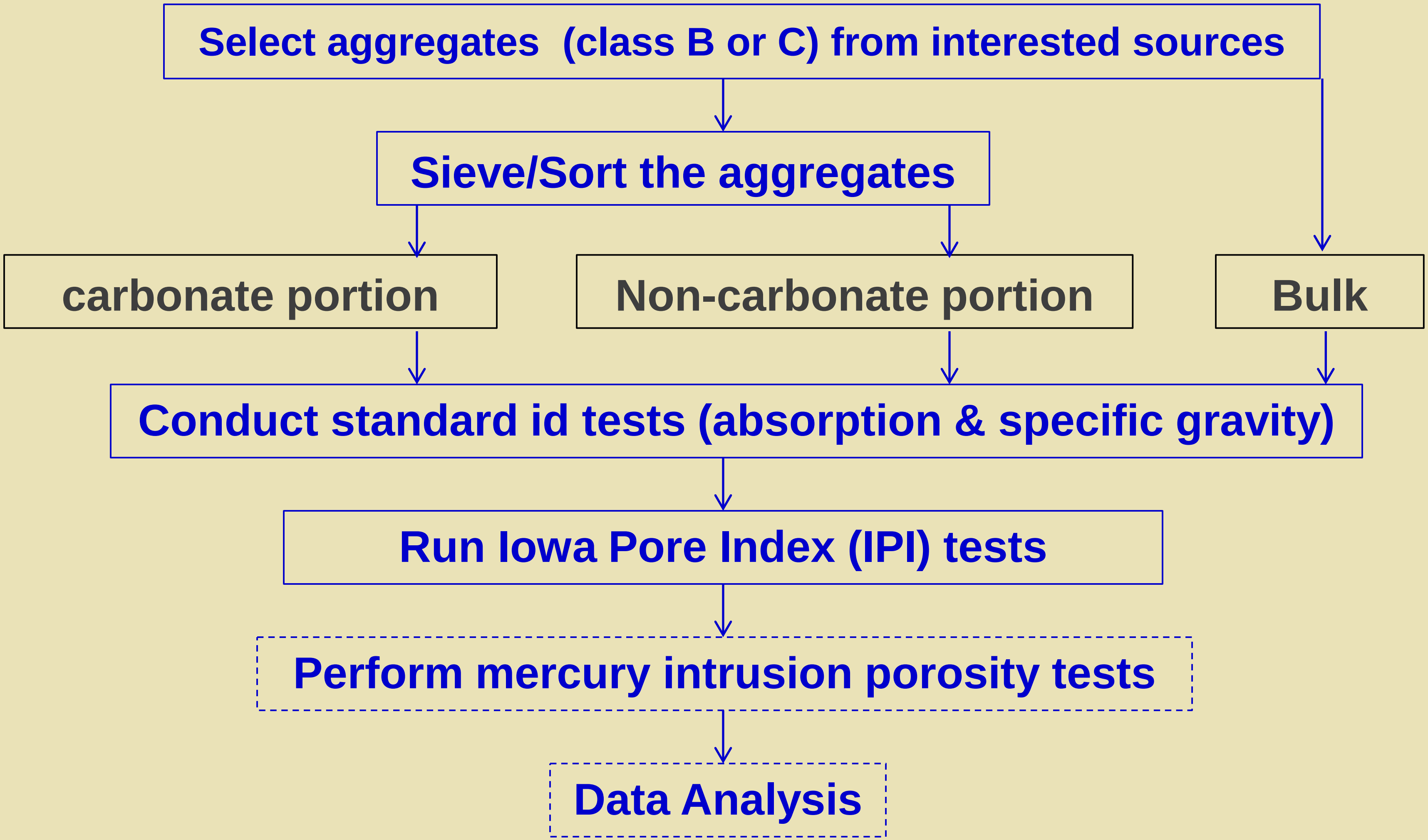
Class C aggregate shall consist of natural or partly crushed natural gravel obtained from a natural gravel deposit. It may contain a quantity of material obtained from crushing the oversize stone in a deposit, provided such crushed material is uniformly mixed with the natural, uncrushed particles.

Objectives

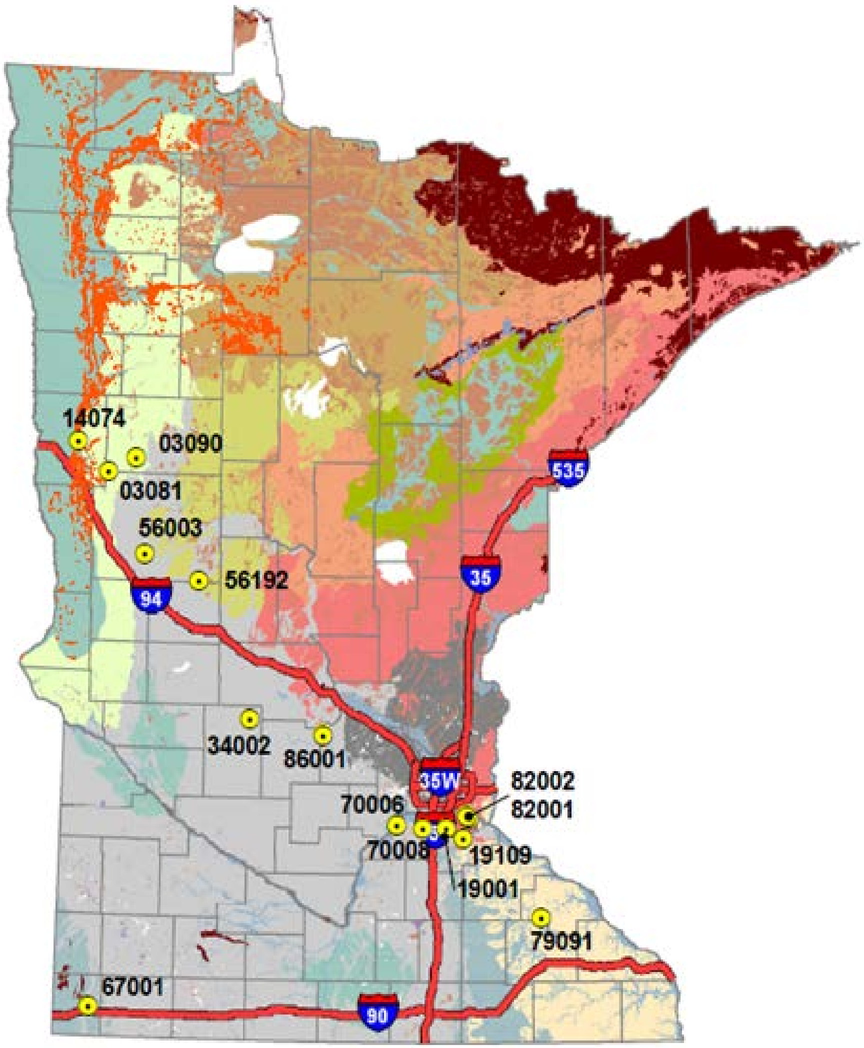
- The goal of the project is to increase use of "non-durable" carbonate aggregate in concrete

- Specific objectives of the project are
  - Explore simple and quick aggregate evaluation methods (Iowa Pore Index Test)
  - Re-evaluate the criteria for MN aggregate acceptance
  - Examine aggregate pore structure and its relationship with the aggregate performance

Methodology



Aggregates Selected



Source ID No.	Carbonate Content, %
03081	~23
03090	23
14074	25
19001	20
19109	14
34002	41
56003	23
56192	44
67001	25
70006*	100
70008	21
79091*	100
82001	14
82002*	100
86001	29

15 different aggregate sources

12 are natural gravel(carbonate = 14 - 44%)

3 are 100% carbonate

Iowa Pore Index (IPI) Test -Dr.Dawson

Sample preparation:

Aggregate was sieved to obtain ½-in. to ¾-in. fraction, washed and dried, then sorted to carbonate and non-carbonate por…

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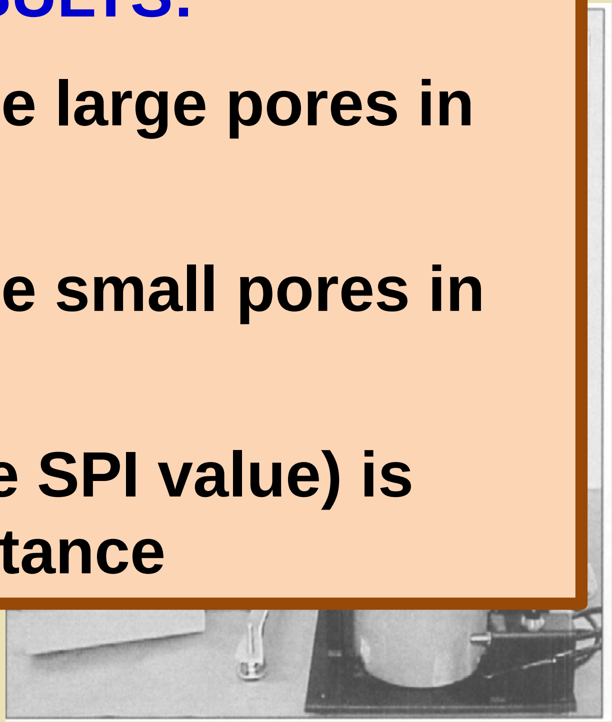
The… minutes is then measured and defined as **Secondary Pore Index (SPI).**



INTERPRETION OF THE TEST RESULTS:

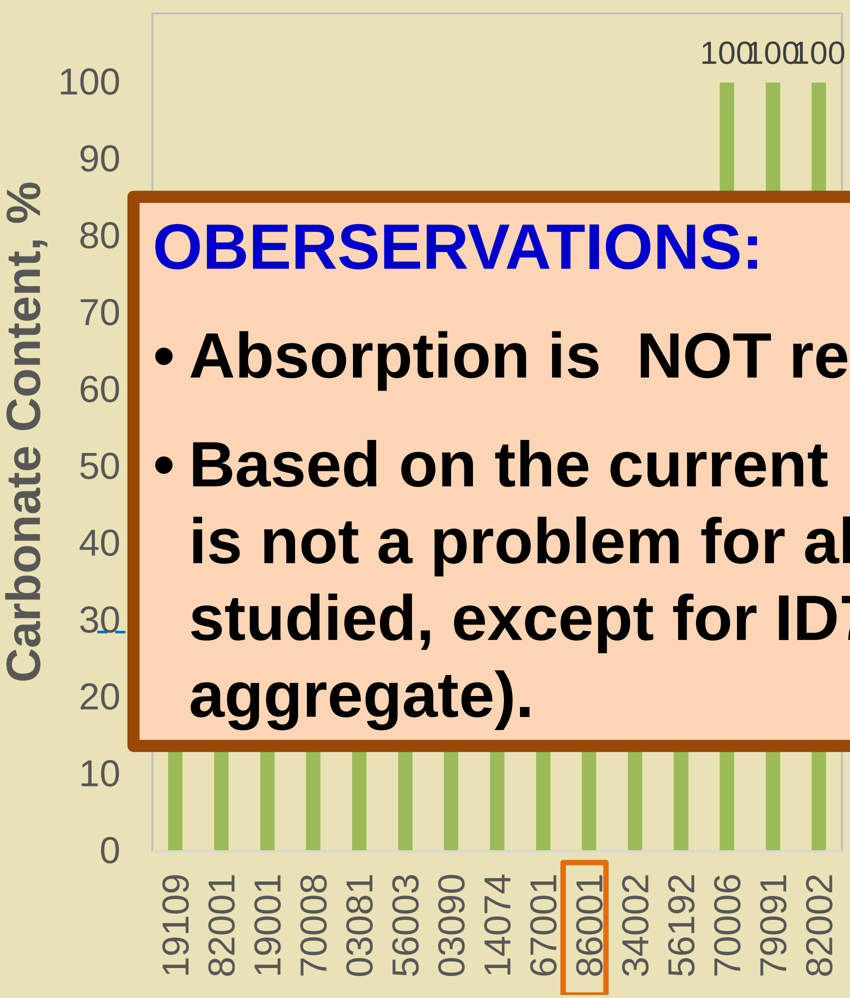
- **The higher the PPI value, the more large pores in the aggregate.**
- **The higher the SPI value, the more small pores in the aggregate.**
- **The amount of small pores (or the SPI value) is related to the aggregate F-T resistance**

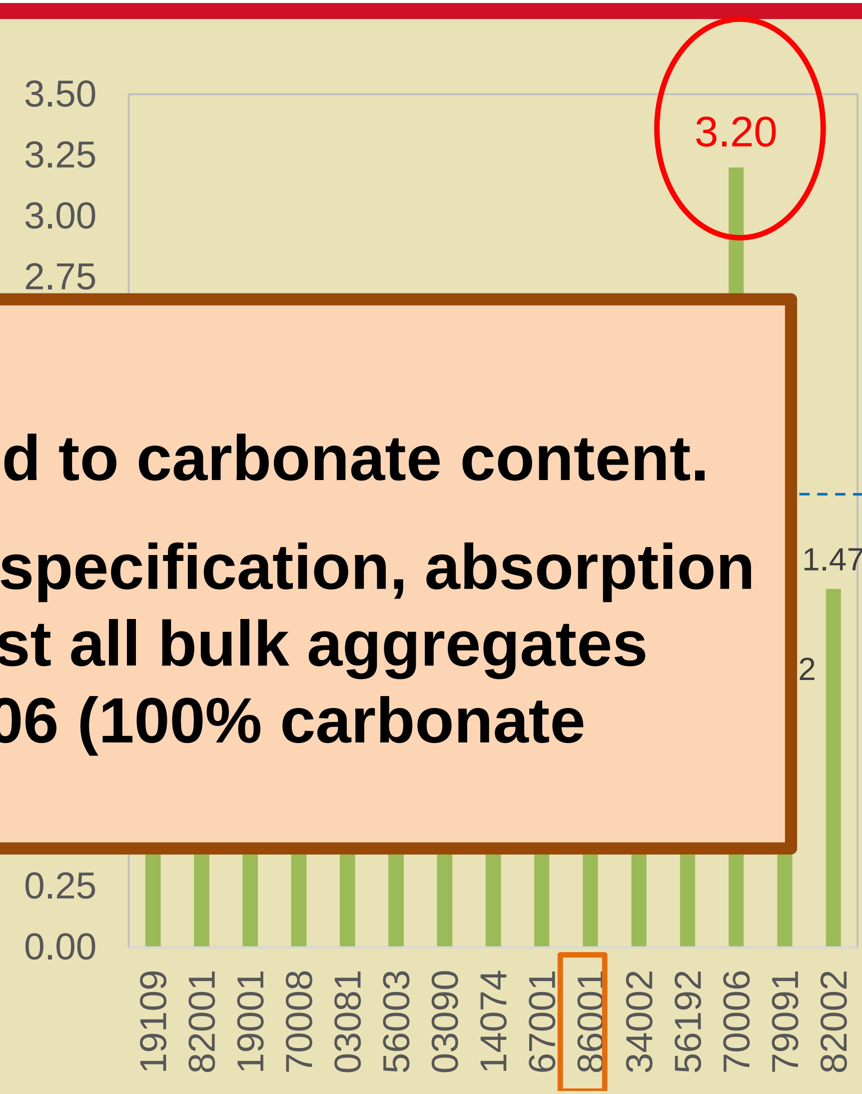
Test Results
(Carbonate, Non-carbonate, & Bulk Portions)

Aggregate ID		Absorption, %	Specific Gravity (OD)	PPI	SPI
03081	C	1.87	2.58	101	35
	N-C	0.44	2.66	51	7
	Bulk	0.65	2.63	67	16
03090	C	1.89	2.64	89	31
	N-C	0.52	2.73	53	7
	Bulk	0.82	2.72	74	16
14074	C	1.84	2.61	107	31
	N-C	0.54	2.67	53	7
	Bulk	0.80	2.65	62	10
19001	C	2.69	2.56	133	21
	N-C	1.01	2.69	63	17
	Bulk	1.32	2.65	73	18
19109	C	2.66	2.55	129	33
	N-C	1.04	2.67	68	18
	Bulk	1.30	2.66	84	20
34002	C	2.35	2.55	102	32
	N-C	0.74	2.65	60	9
	Bulk	1.47	2.63	83	22
56003	C	1.85	2.57	88	29
	N-C	0.72	2.64	49	11
	Bulk	0.91	2.65	68	18

Aggregate ID		Absorption, %	Specific Gravity (OD)	PPI	SPI
56192	C	1.91	2.63	97	31
	N-C	0.51	2.70	47	5
	Bulk	1.25	2.68	80	18
67001	C	2.54	2.56	129	23
	N-C	1.38	2.63	88	17
	Bulk	1.64	2.61	116	20
70006	C	3.20	2.54	129	53
70008	C	2.07	2.59	124	32
	N-C	0.87	2.70	59	14
	Bulk	1.04	2.67	64	16
79091	C	1.02	2.73	77	18
82001	C	2.28	2.61	113	27
	N-C	0.89	2.61	64	15
	Bulk	1.14	2.68	92	20
82002	C	1.47	2.70	86	22
86001	C	2.49	2.56	113	29
	N-C	1.00	2.68	59	15
	Bulk	1.37	2.65	81	23

Carbonate Content & Absorption (Bulk)





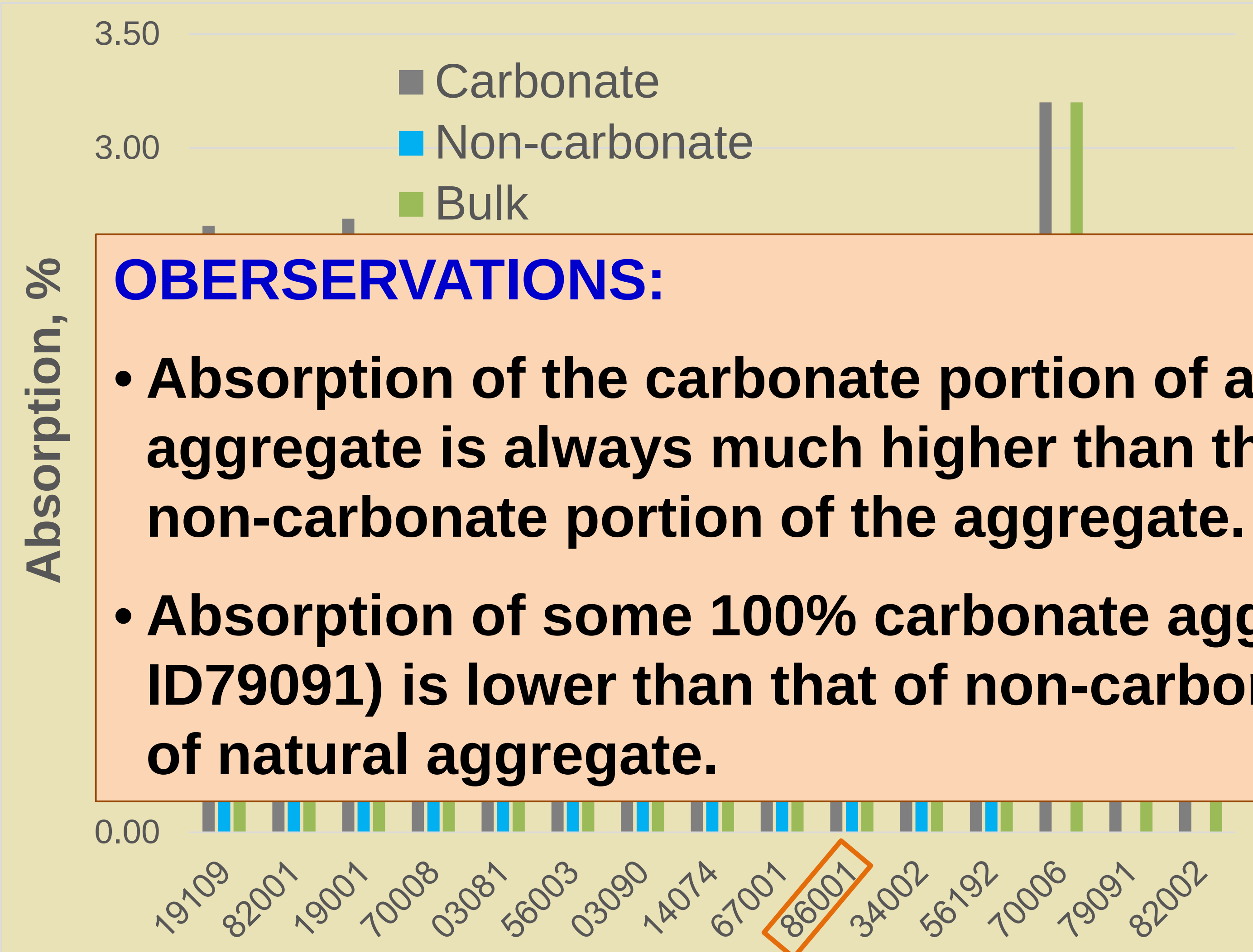
OBERSERVATIONS:

- **Absorption is NOT related to carbonate content.**
- **Based on the current Mn specification, absorption is not a problem for almost all bulk aggregates studied, except for ID70006 (100% carbonate aggregate).**

13.5% Carbonate content→28.5%→100%

13.5% Carbonate content→28.5%→100%

Absorption
(Carbonate & Non-carb Portions)



For natural gravel

Carbonate Portion

(all >1.75%)

OBERSERVATIONS:

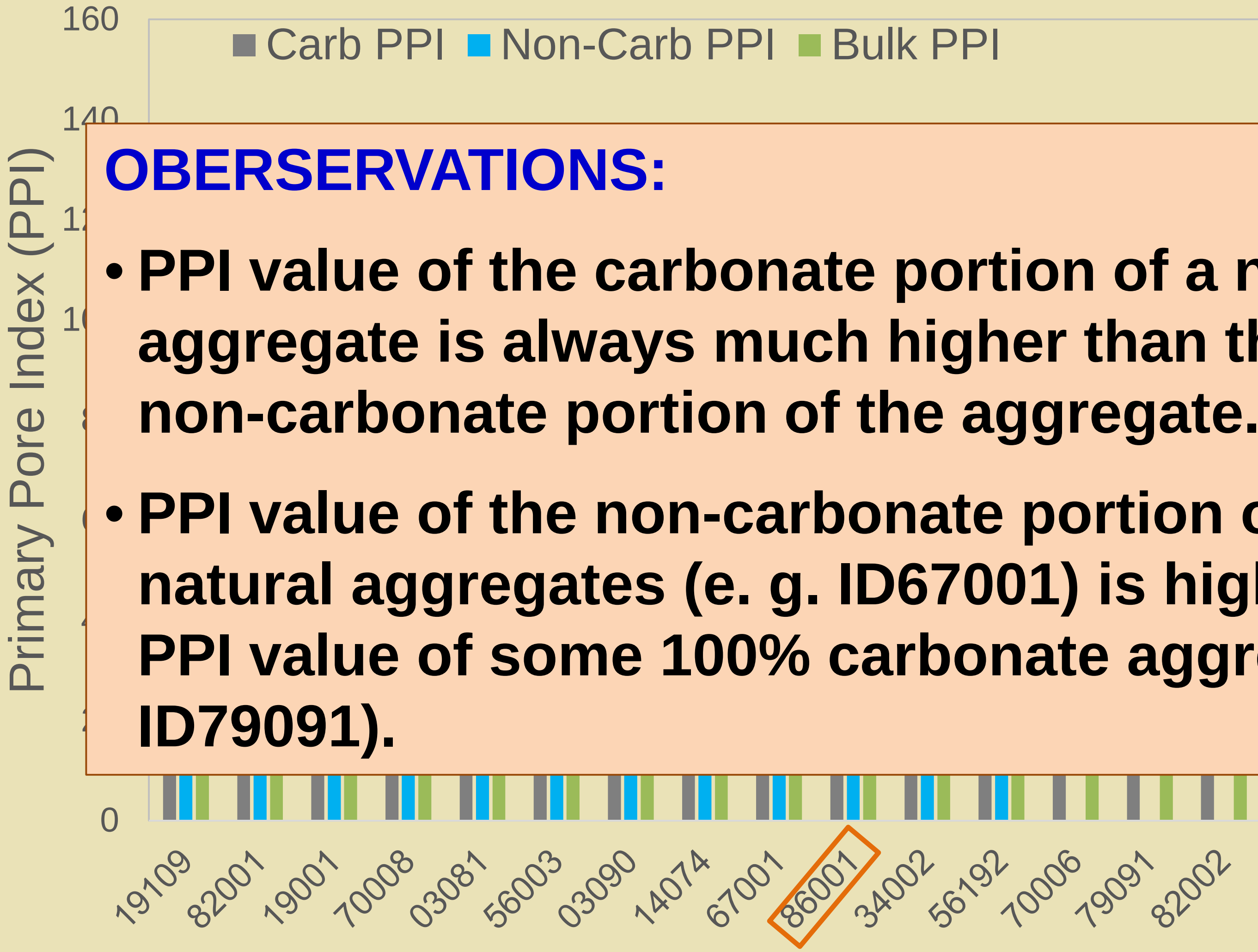
- **Absorption of the carbonate portion of a natural aggregate is always much higher than that of the non-carbonate portion of the aggregate.**
- **Absorption of some 100% carbonate aggregate (e. g. ID79091) is lower than that of non-carbonate portion of natural aggregate.**

e

1.02, 1.50 , 3.20%

13.5% Carbonate content → 28.5% → 100%

Primary Pore Index (PPI)
(Carbonate, Non-carb, & Bulk Portions)



A high PPI value indicates more
the
ate.

OBERSERVATIONS:

- **PPI value of the carbonate portion of a natural aggregate is always much higher than that of the non-carbonate portion of the aggregate.**
- **PPI value of the non-carbonate portion of some natural aggregates (e. g. ID67001) is higher than the PPI value of some 100% carbonate aggregate (e. g. ID79091).**

vel

on

100% carbonate aggregates

77, 80, 129

13.5% Carbonate content → 28.5% → 100%

Secondary Pore Index (SPI)
(Carbonate, Non-carb , & Bulk Portions)

OBERSERVATIONS:

- **SPI value of the carbonate portion of a natural aggregate is always much higher than that of the non-carbonate portion of the aggregate.**
- **The differences in the SPI value between carbonate and non-carbonate portions vary depending upon the sources of the aggregates.**
- **Among three 100% carbonate aggregates, ID 70006 had much higher absorption, PPI and SPI values than other two aggregates, indicating that ID 70006 might be problematic.**

18, 22, 53

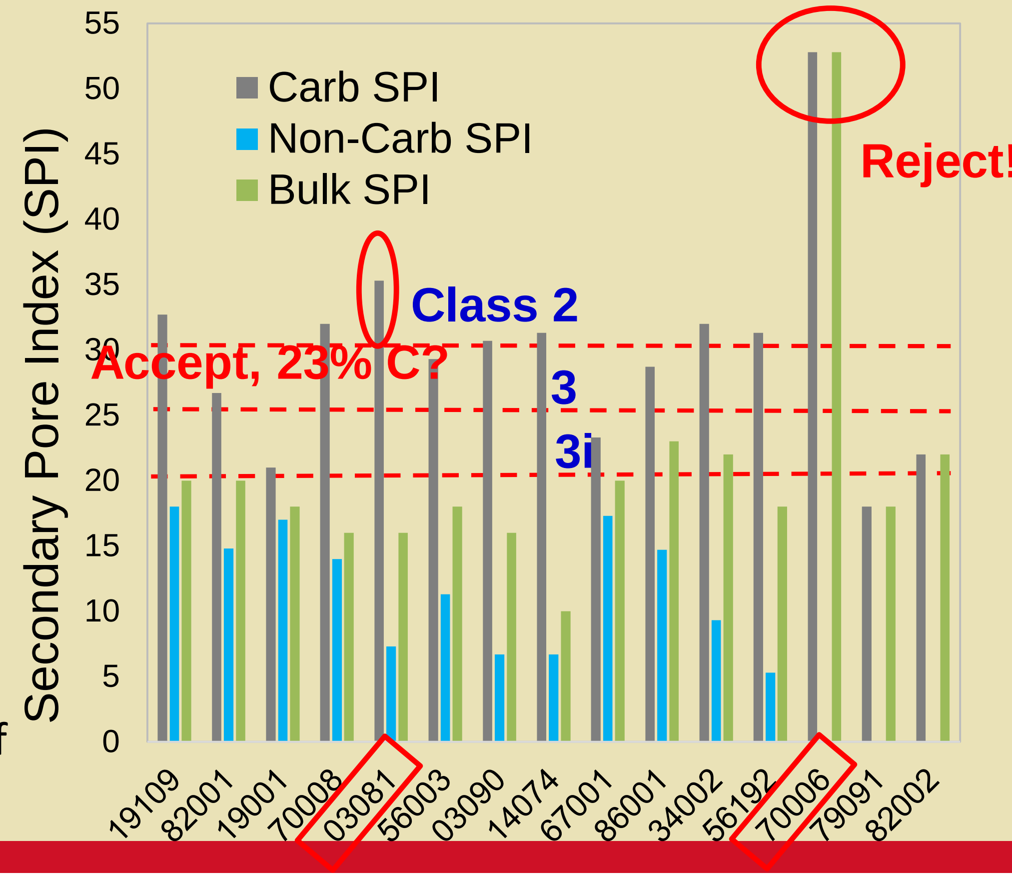
13.5% Carbonate content → 28.5% → 100%

Iowa DOT Specification

Iowa DOT IM 409 (Iowa DOT, 2013):

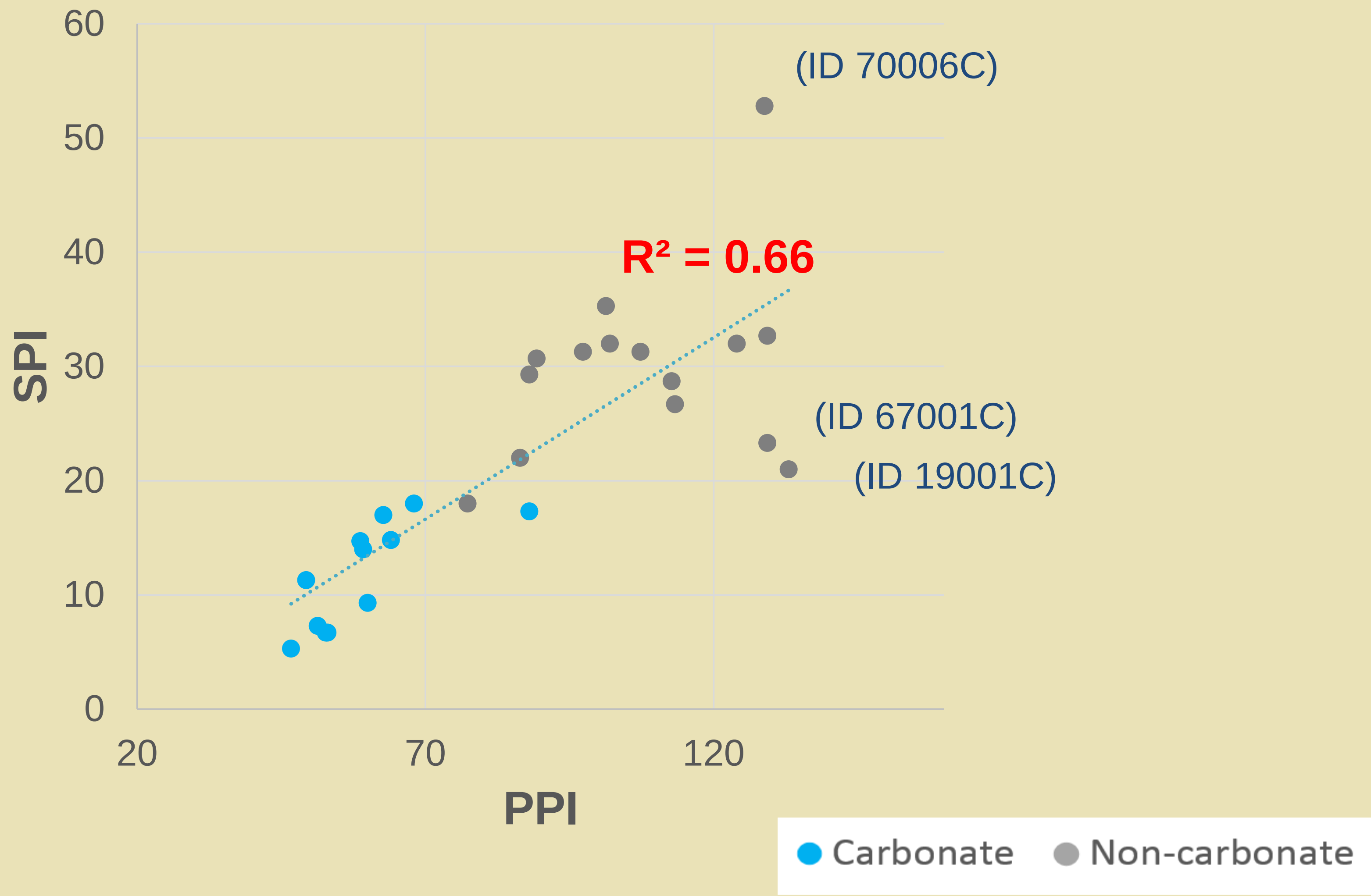
- **Class 2**: aggregates will produce no deterioration of pavements of the non-Interstate segments of the road system after 15 years and only minimal deterioration in pavements after 20 years of age
- **Class 3**: aggregates will produce no deterioration of pavements of non-Interstate segments of the road system after 20 years of age and less than 5% deterioration of the joints after 25 years
- **Class 3i**: durability aggregates will produce no deterioration of the interstate road system after 30 years of service and less than 5% deterioration of the joints after 35 years

If there is no performance history for the aggregate, secondary pore index must be less than 30, 25 or 20 for Class 2, 3 and 3i ratings, respectively.

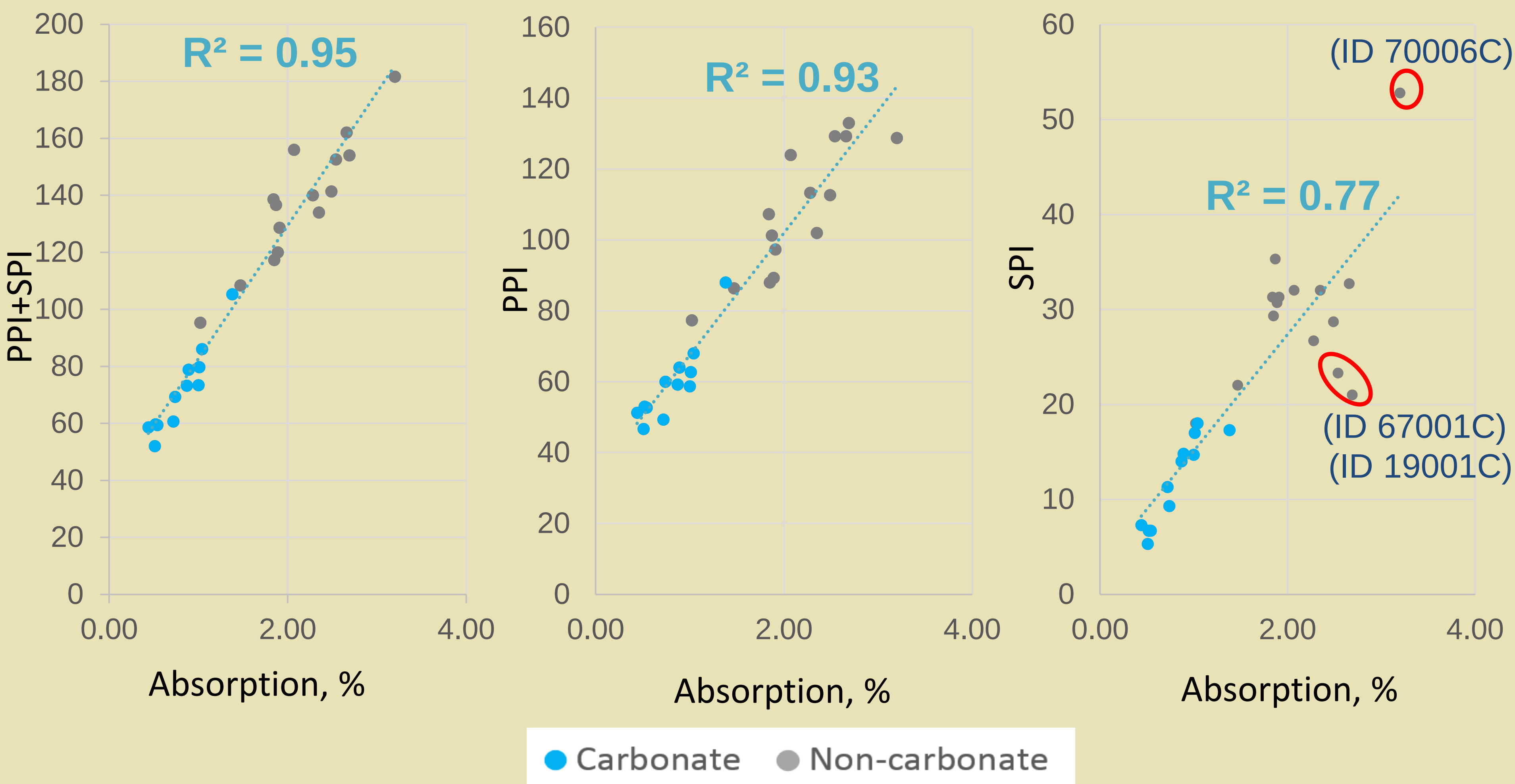


13.5% Carbonate content→ 28.5% → 100%

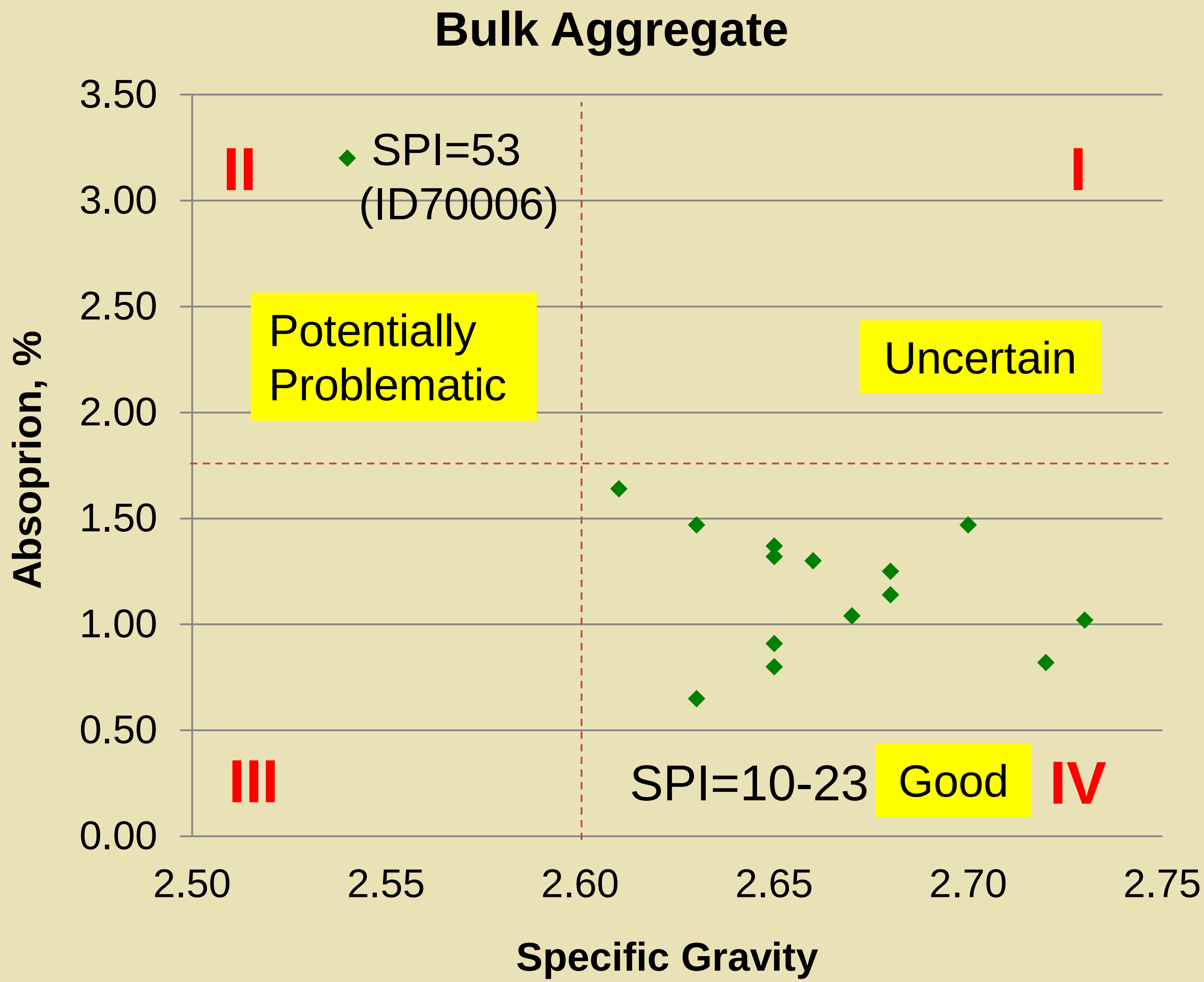
Relationship Between PPI and SPI



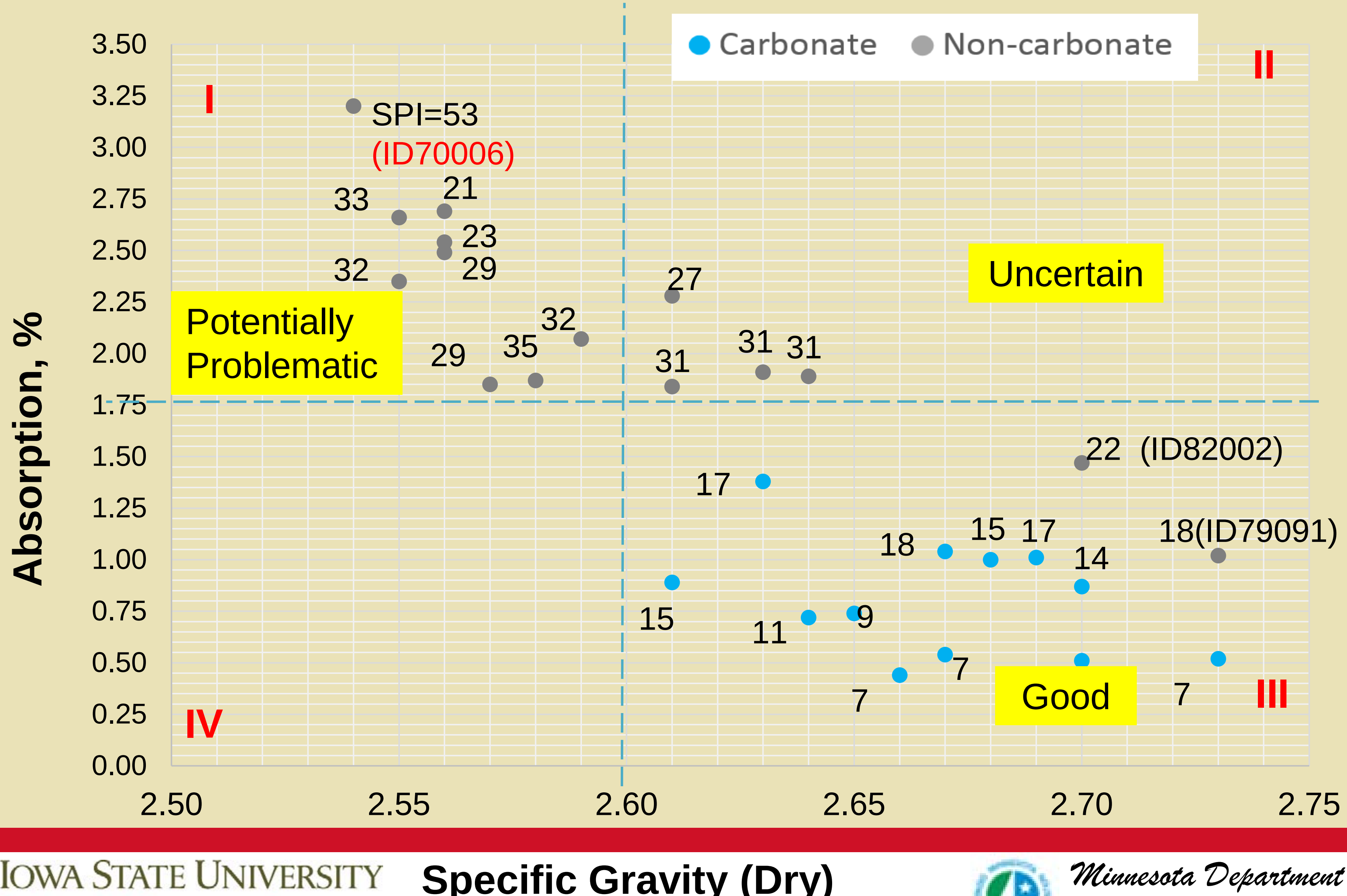
Relationship Between Pore Index & Absorption



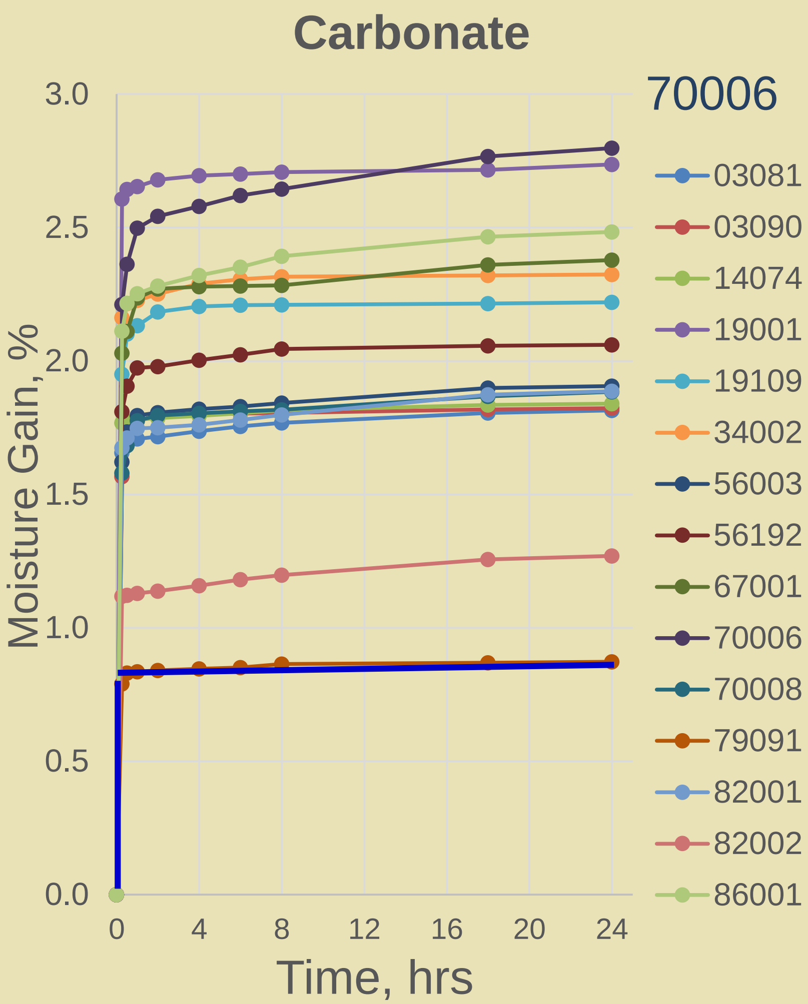
Absorption, Specific Gravity, and SPI

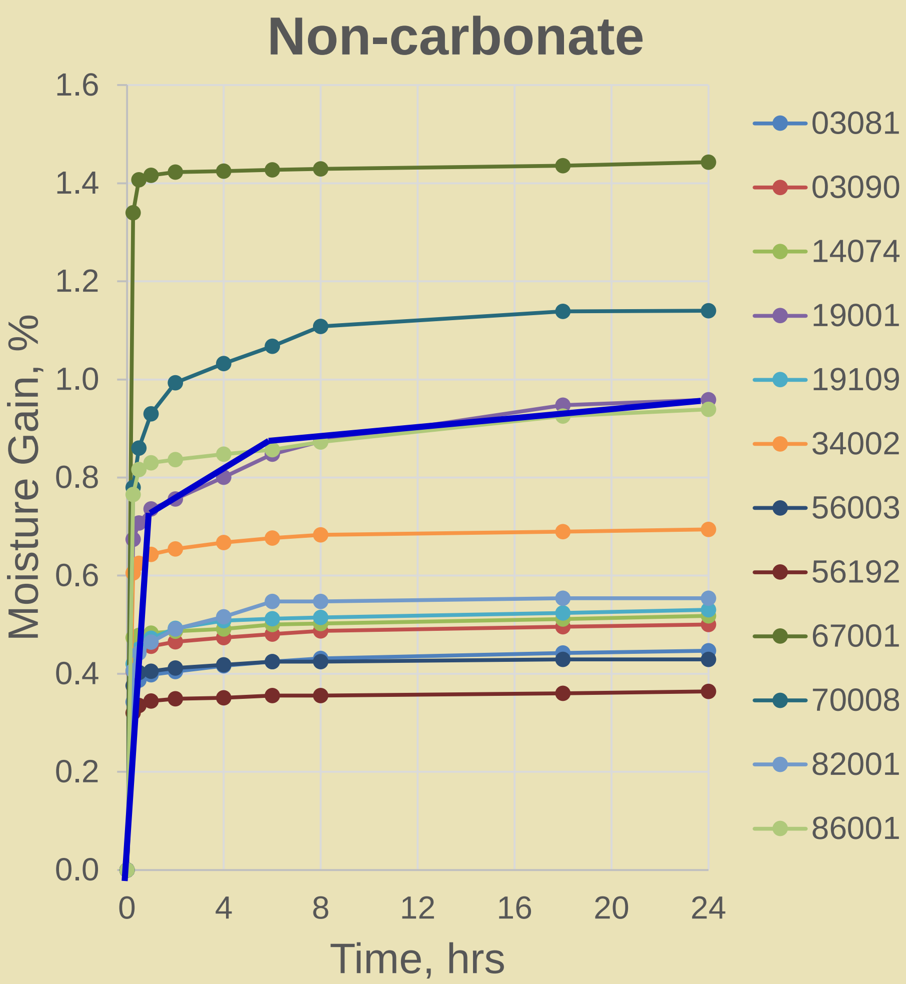


Absorption, Specific Gravity, and SPI



Rate of Water Absorption





Almost all reached >95% total absorption in 30 min.

Effect of Pore Size on Rate of Absorption

Permeability (K), or rate of water flow, depends on pore properties such as their shape, number, orientation and continuity.

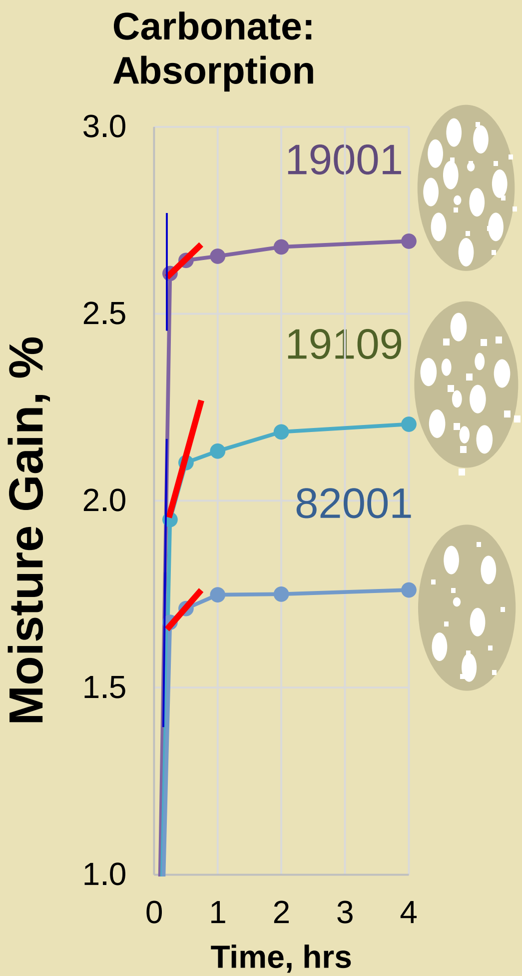
Numerous theoretical and empirical attempts have been made to define the relation between permeability and these factors.

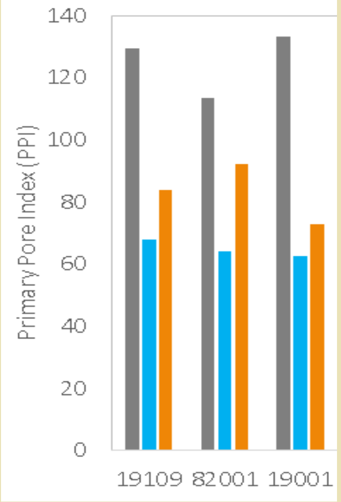
Hazen (1911) and Swanson (1977) suggested the approximation:

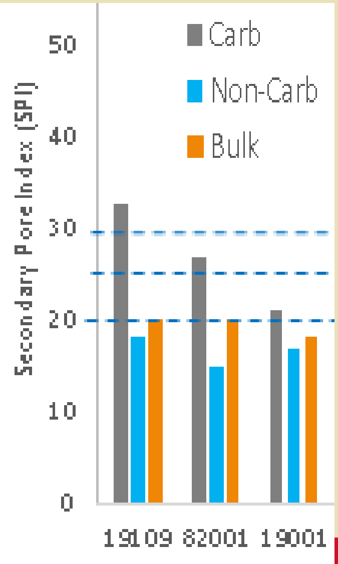
$$K = cD^2$$

where *c is a dimensionless coefficient representing the sphericity or roundness of the* pores; and *D is the mean pore diameter.*

Assume c is constant for a given aggregate, K is proportional to D^2.







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Concluding Remarks

- There is no relationship between carbonate content and absorption/IPI
- Some 100% carbonate aggregates (ID 82002 & 79091) had lower absorption, PPI, and SPI values than natural gravel

→ Using the limitation of 30% carbonate content as aggregate acceptance criteria may not be rational.

- There is a good relationship between PPI and SPI
- Absorption is very closely related to both PPI & SPI

→ *Using an absorption limit as aggregate acceptance criteria doesn't provide any information on the amount of large (PPI) or small (SPI) sizes of aggregate.*

- IPI tests have been studied by several DOTs, but it is still not clear how PPI & SPI values relate to pore size distribution of the aggregate.

→ *Further study is needed to relate PPI & SPI to the pore size of aggregate.*

Research in Progress

Initial Study of Aggregate Pore Structure

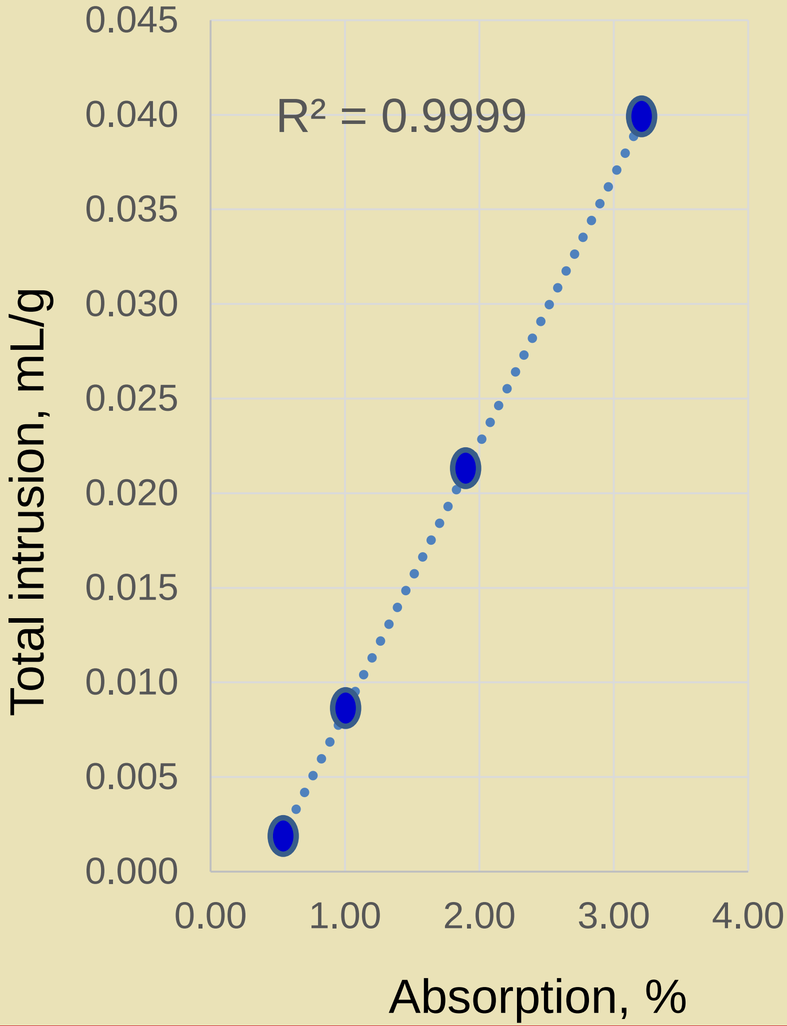
Critical Pore Sizes Range Obtained for D-Cracking

Study	Critical Pore Size (μm)	Comments on Study
Shakoor 1982	0.01–10	Pore size was determined based on freeze-thaw results on aggregates subjected to 5% NaCl solution.
Salcedo 1984	0.045–10	Temperature and rate of temperature change was considered in determining the critical pore size for aggregates subjected to freeze-thaw.
Dubberke and Marks 1985	0.04–0.2	Critical Pore size was determined for aggregates subjected to deicer salts

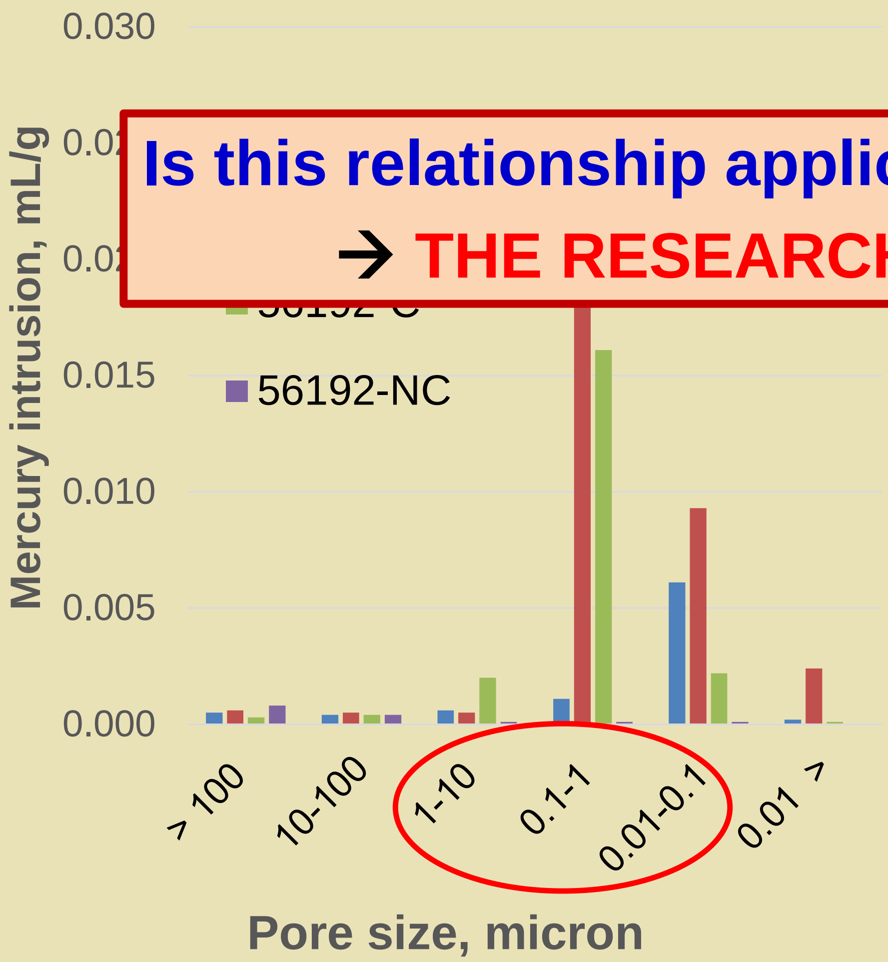
From Mummaneni & Riding, K-TRAN: KSU-10-9, 2012

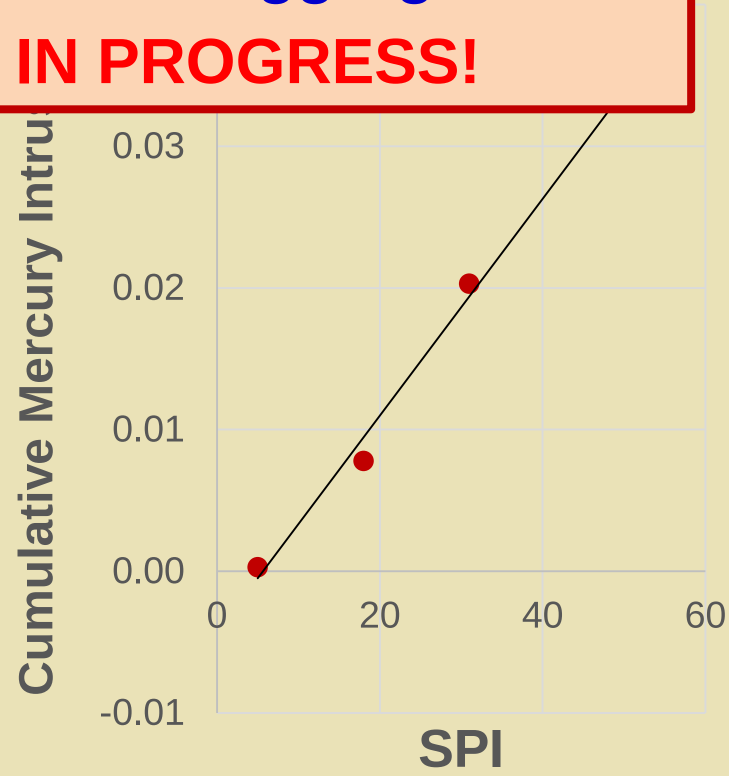
Initial Mercury Intrusion Porosimetry (MIP) Test Results

Aggregate ID	79091	70006	56192-C	56192-NC
Absorption	1.02	3.20	1.91	0.51
Specific Gravity	2.73	2.54	2.63	2.70
PPI	77	129	97	47
SPI	18	53	31	5
Bulk Density	2.76	2.55	2.67	2.89
Total intrusion, mL/g	0.0089	0.0397	0.0211	0.0015



Initial MIP Data Analysis





Is this relationship applicable to all aggregates?

→ THE RESEARCH IS IN PROGRESS!

Thank you!

Questions?

Before F-T

After 50 F-T cycle

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