A method to rapidly predict service life and susceptibility to deicing salt deterioration of aggregates used in Portland cement concrete

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SMARTER | SIMPLER | CUSTOMER DRIVEN

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Background

- ASTM 666 Durability Beams were used for aggregate source approvals as a predictor of pavement performance.
- This test did not catch aggregates that were susceptible to early deterioration when exposed to deicing salts.
- In the late 1970’s to the mid 80’sWendell Dubburke developed the Iowa Pore Index test and began collecting aggregate chemistry data.

Background

- In the mid 1980's Wendell proposed an algorithm that combined the pore index with aggregate chemistry to predict durability class.
- This algorithm using the pore index, chemistry, mineral structure and TGA became part of the approval specifications in 2000 (referred to here as Method B).
- After 10 years evaluation, revisions to the algorithm were proposed (Method A).

Research Objectives

- Develop methods to quickly predict the performance of an aggregate source in PCC.
- Two separate test algorithms have been developed and compared.
- Discussion today will describe the more recent algorithm (Method A). It has now been evaluated for three years.
- The evaluation included review of historic data.

Types of Aggregate Tested and Common to Iowa

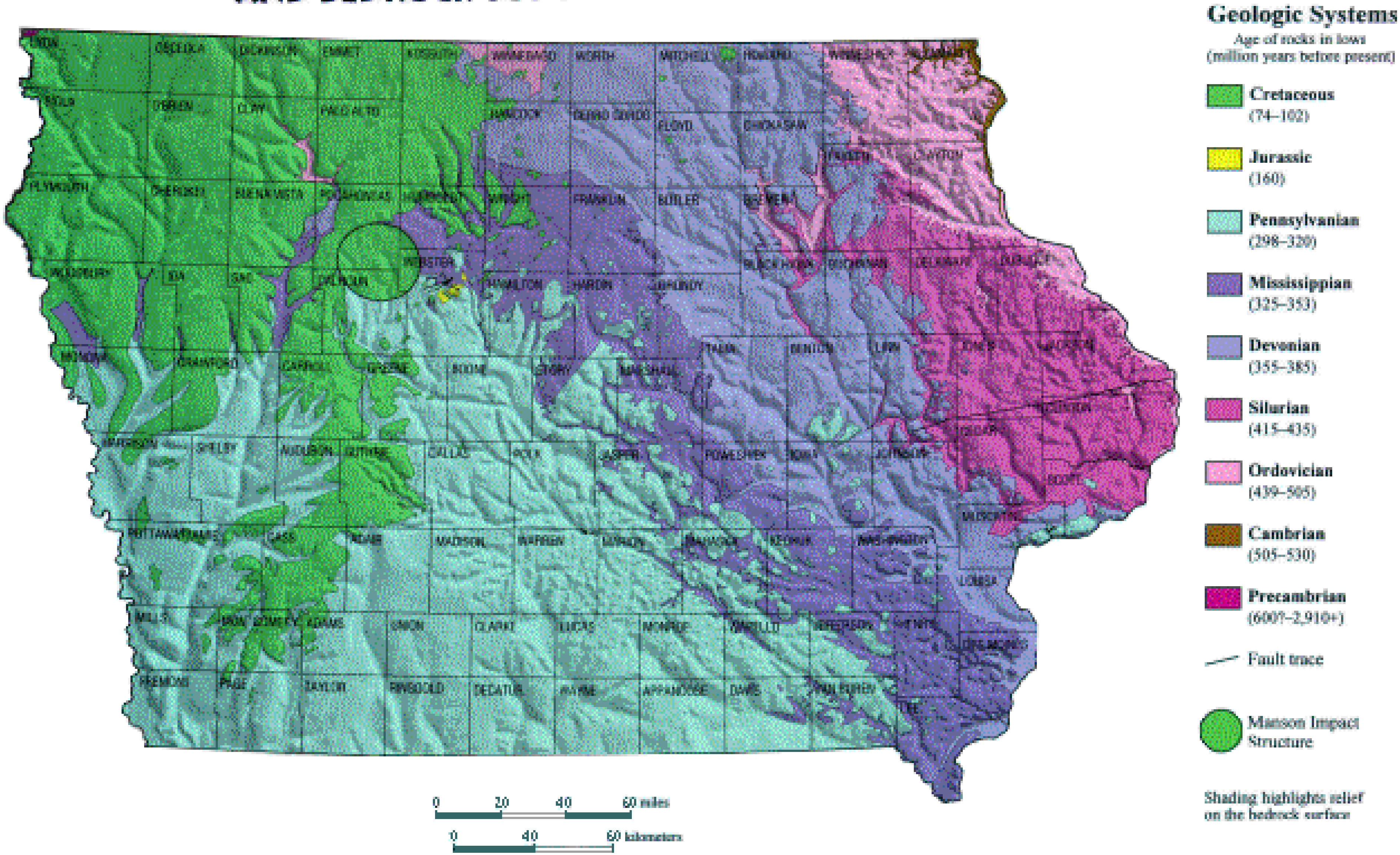
- Limestone - $CaCO_3$
- Dolomite - $CaMg(CO_3)_2$
- Intermediate Dolomites
- Carbonate fraction of a Gravel

Why there was a need to develop a predictive tool

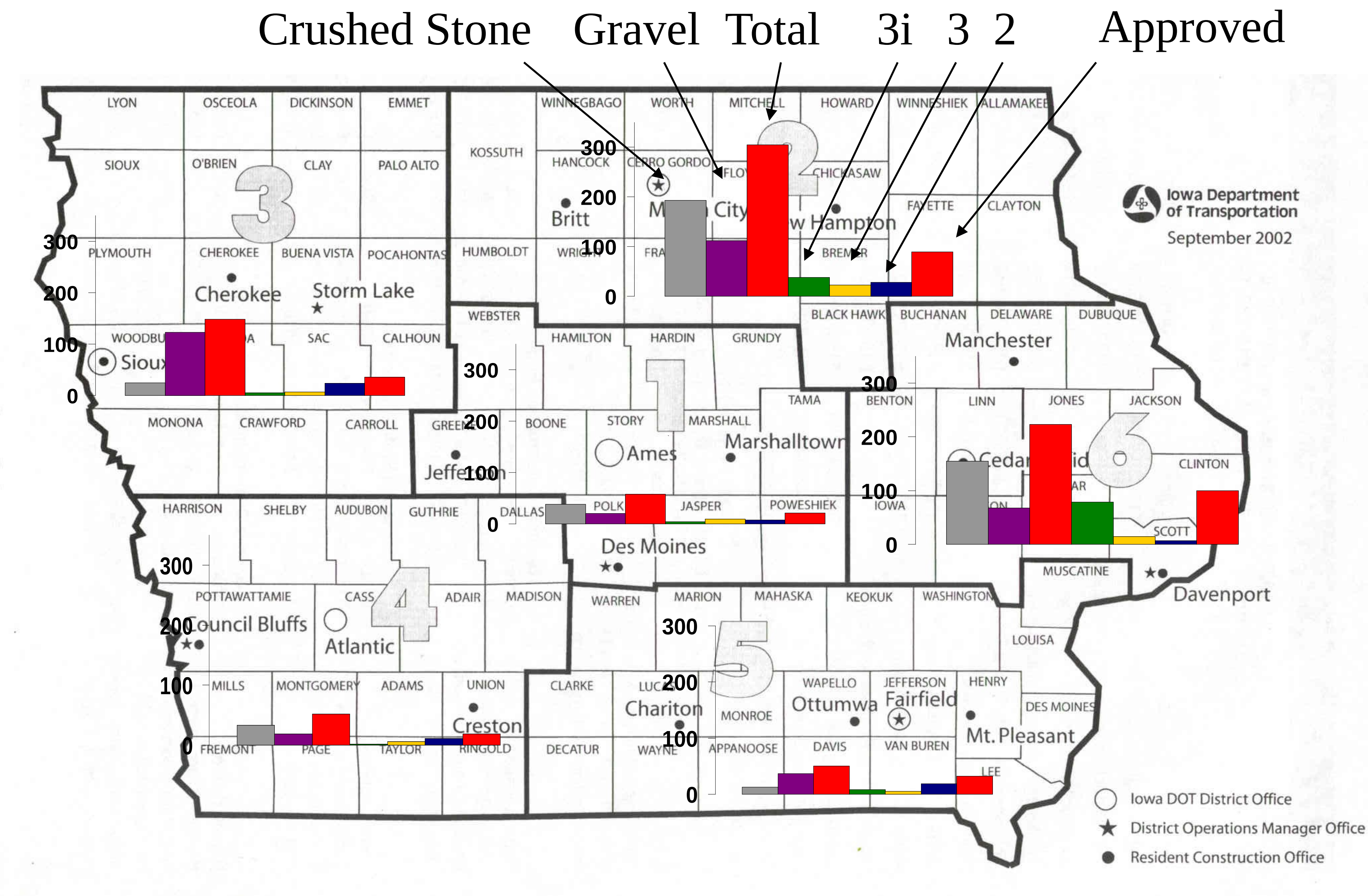
In Iowa aggregates range from very high quality to not approvable

- The necessity of developing a method to predict aggregate performance is due to the diverse range of aggregate quality in the State.
- Limestone in Iowa formed as oceans invaded the central continent many times over about 400 million years.

BEDROCK GEOLOGY AND BEDROCK TOPOGRAPHY OF IOWA



Aggregate Sources by District



What are the results of using an incorrectly characterized aggregate?

Material Related Distress

- Due to poor aggregate
- Initial observed as staining of the joints
- Progressive deterioration seen as fractures at the transverse joint

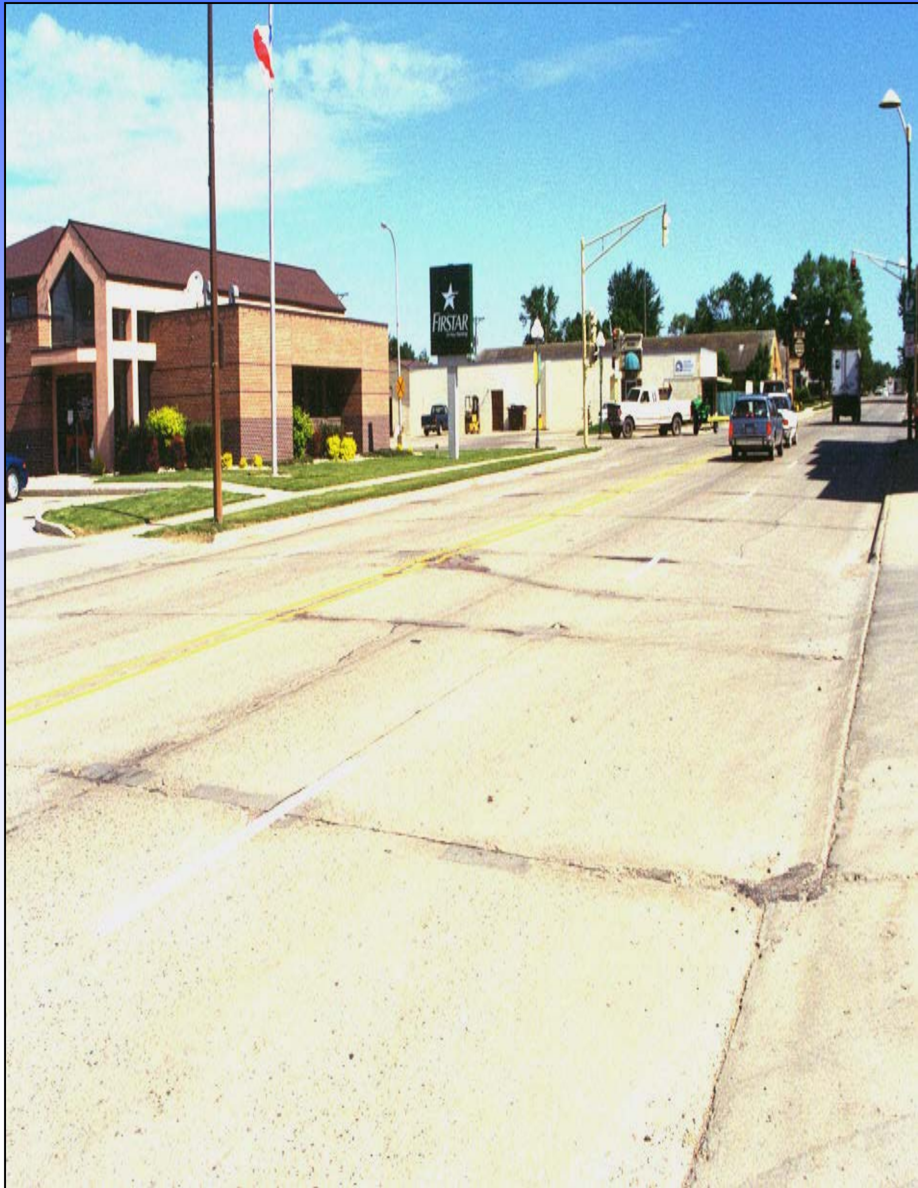
Initial shadowing of the Joints

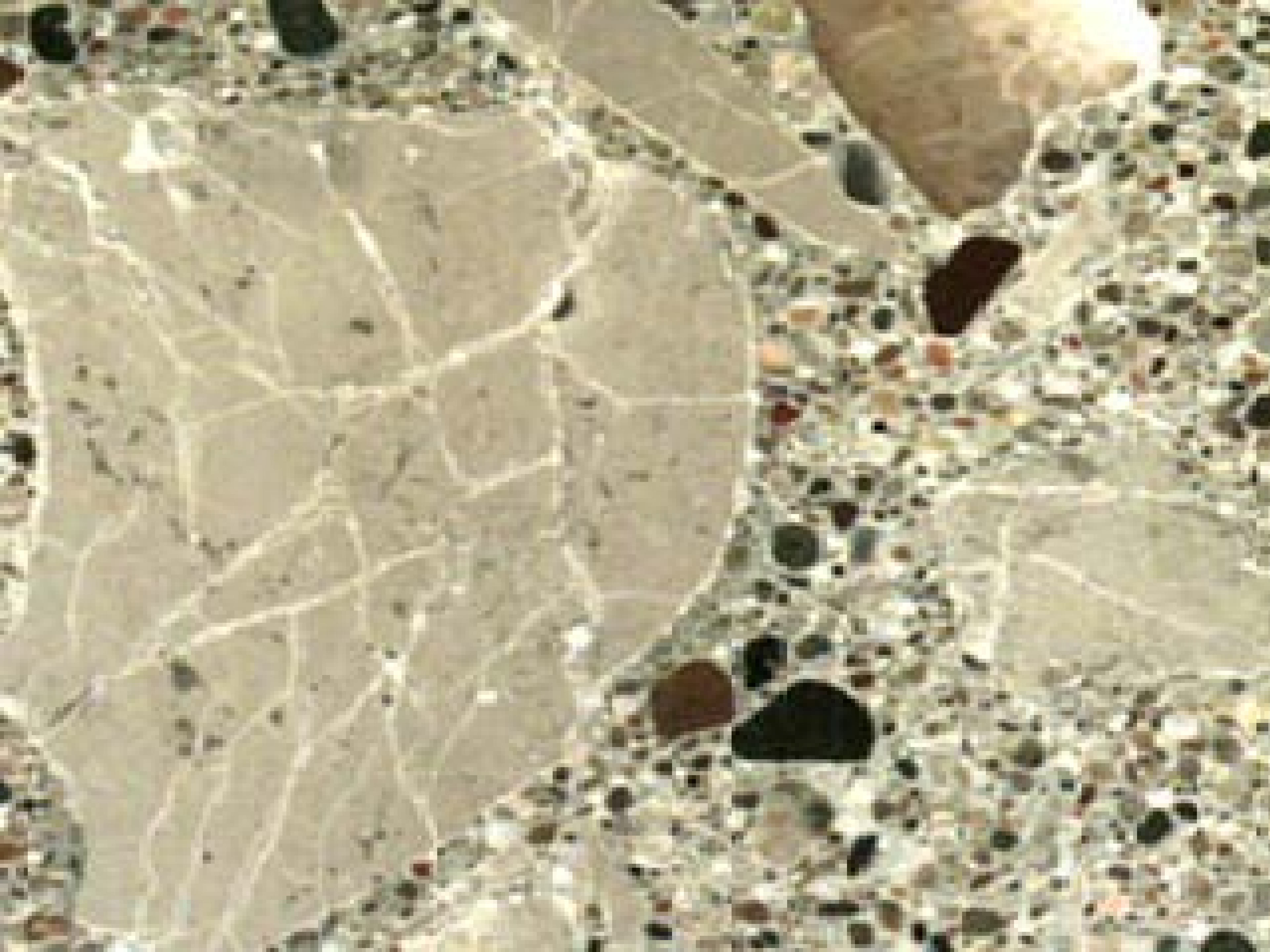
Material Related Distress

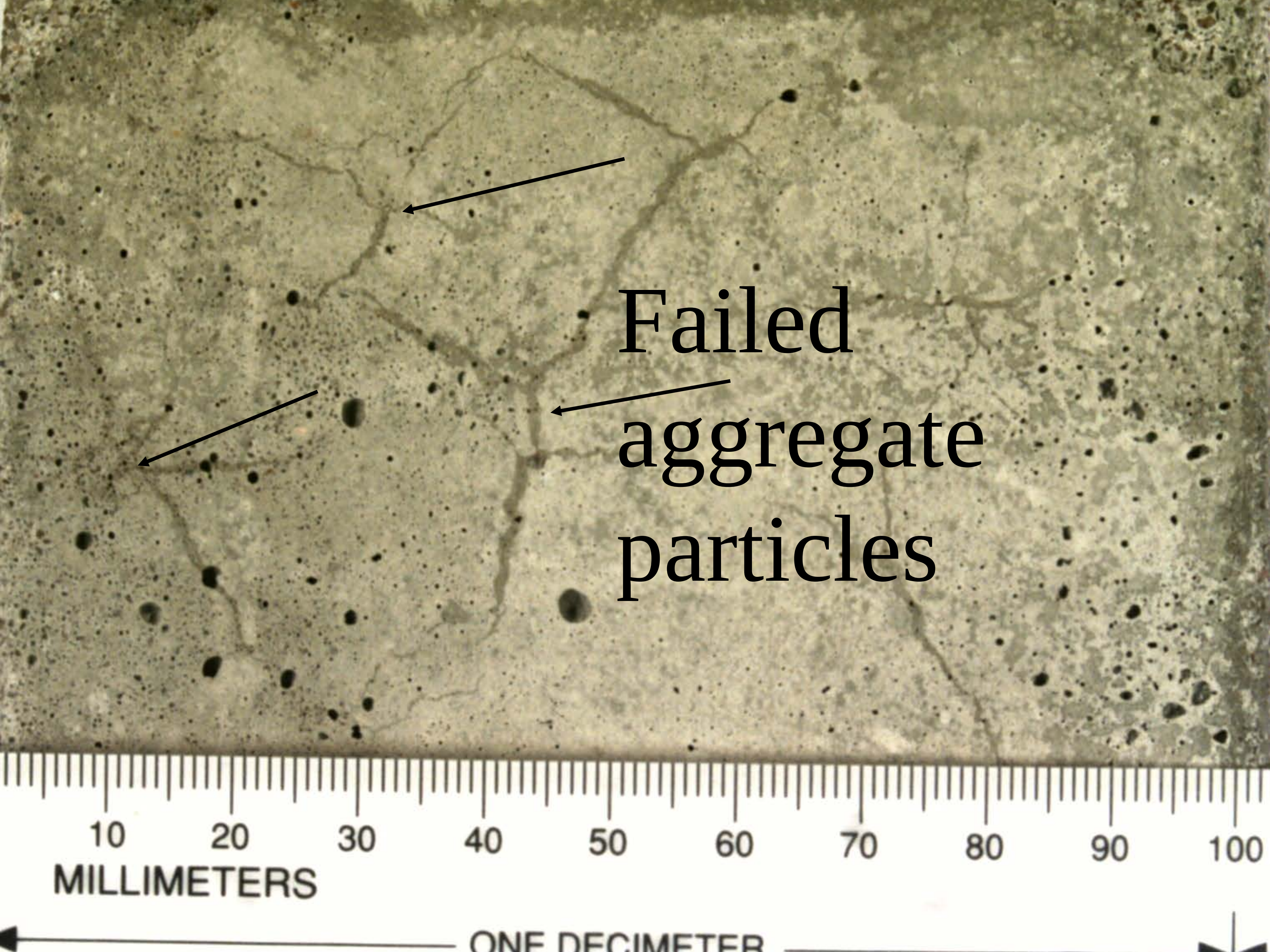
- Decay progresses from the bottom of the slab
- This results in spalling at the joint intersection which may happen in as little as 15 to 20 years.

Progressive deterioration at the transverse joint from the base up.

Deterioration of pavement increases with deicing salting approaching traffic lights with poor aggregates.






Failed
aggregate
particles
10
20
30
40
50
60
70
80
90
100
MILLIMETERS
ONE DECIMETER

Aggregates in Iowa

- Aggregates are usually crushed Limestone, Dolomite, or Gravel.
- Based on service history, three concrete durability classes are used in Iowa for aggregates:

  Unapproved

  Class 2 – minimal deterioration 20 yrs

  Class 3 – minimal deterioration 25 yrs

  Class 3i – minimal deterioration 30 yrs

Determination of a Quality Number to Predict Aggregate Durability Class and Pavement Service History

Principle Reasons for Aggregate Failure

- Clay content of the aggregate.
- Pore system: Capillary pores available for chemical reaction and freeze-thaw deterioration (made worse with deicing salts).
- Chemical reactions due to deicing salts.
Stability of minerals that form the aggregate.

These three factors are evaluated by:

- Measuring the clay content of the aggregate (XRF, alumina quality number).
- Determining the pore system for pore size and volume (Iowa Pore Index quality number).
- Examining the limestone and dolomite fractions for chemistry and mineralogy (XRF/XRD quality number).

PCC Quality Numbers

- Each of these aspects of the aggregate generates their own quality numbers, which are weighted to correlate with service history.
- The three quality numbers are then weighted and combined to generate an overall salt-susceptibility quality number.

PCC Quality Numbers

- Aggregate sources without qualifying performance records or satisfactory similarity to any approved source can be provisionally assigned to a Durability Class based on Salt-susceptibility quality numbers and pore index results.
- Class 3i maximum quality number of 1.0.
- Class 3 maximum quality number of 1.5.
- Class 2 maximum quality number of 4.5.
- Above 4.5 there is no approval.

Determination of the Clay Content of an Aggregate and the Alumina Quality Number

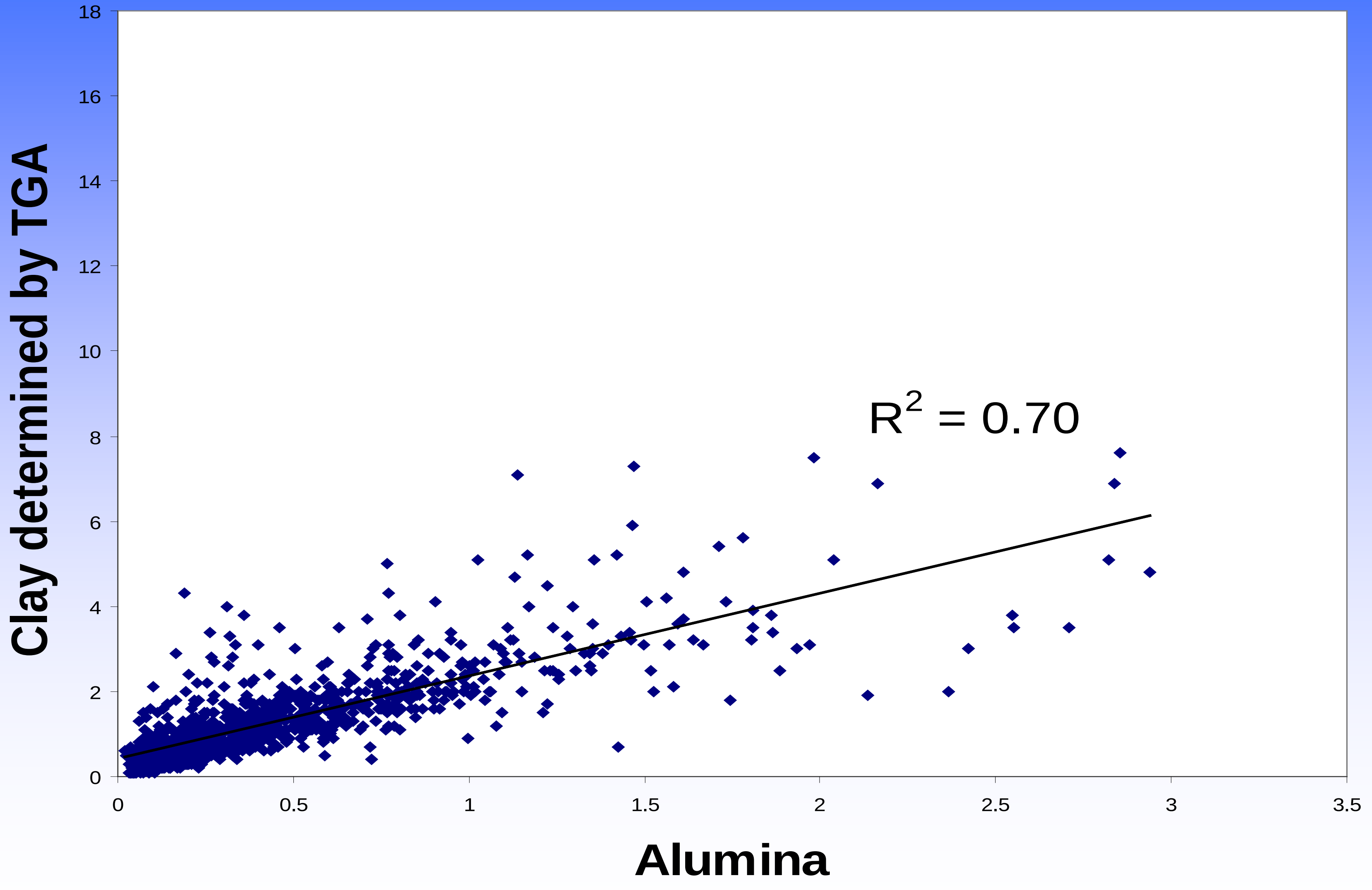
X-Ray Fluorescence (XRF)

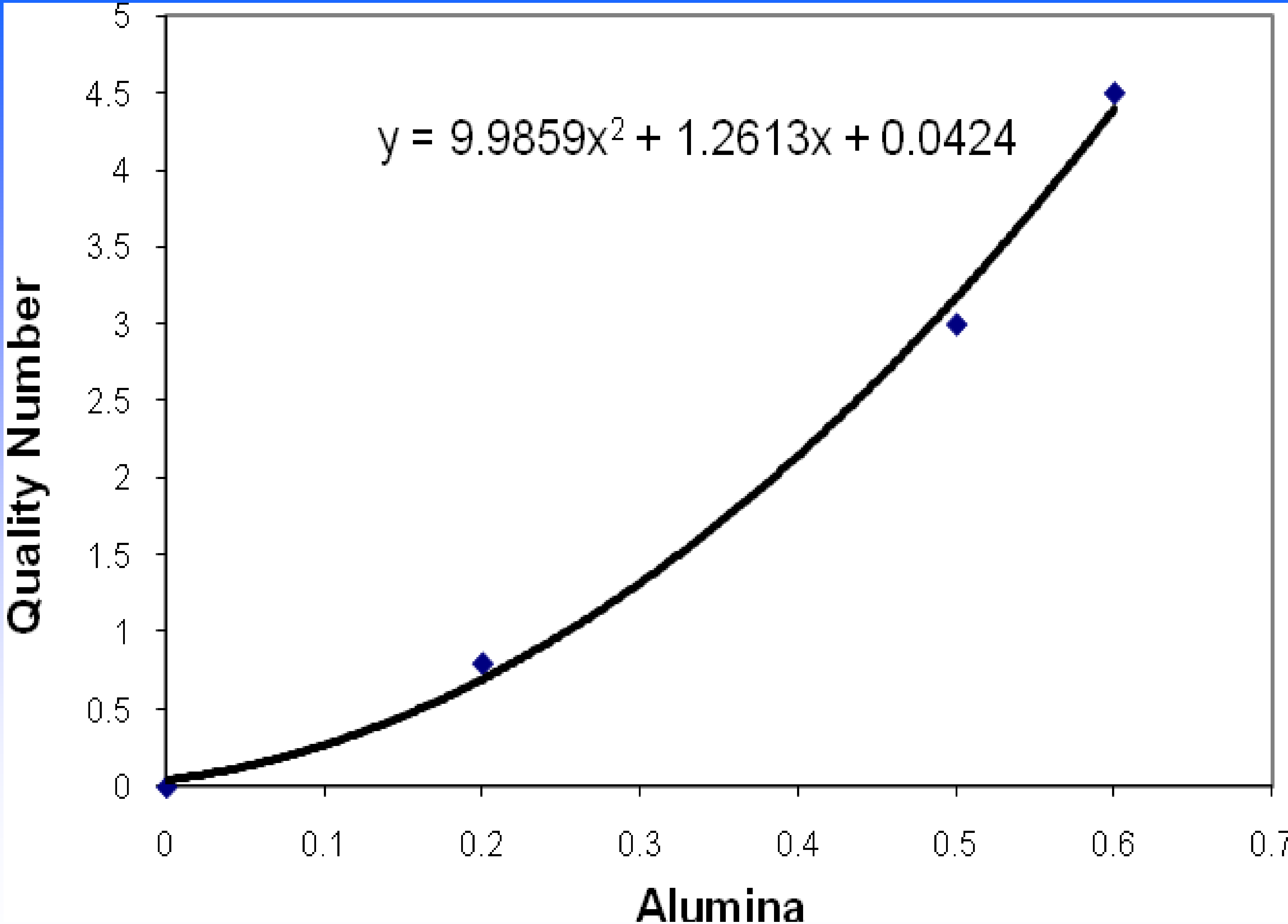
- Is an elemental analysis which determines the bulk composition of a material.
- Results are expressed as oxide percents.
- Oxides determined: CaO, MgO, SiO_2, Al_20_3, Fe_20_3, Cl, TiO_2, S, Na_2O, K_2O, P_2O_5, MnO, SrO.

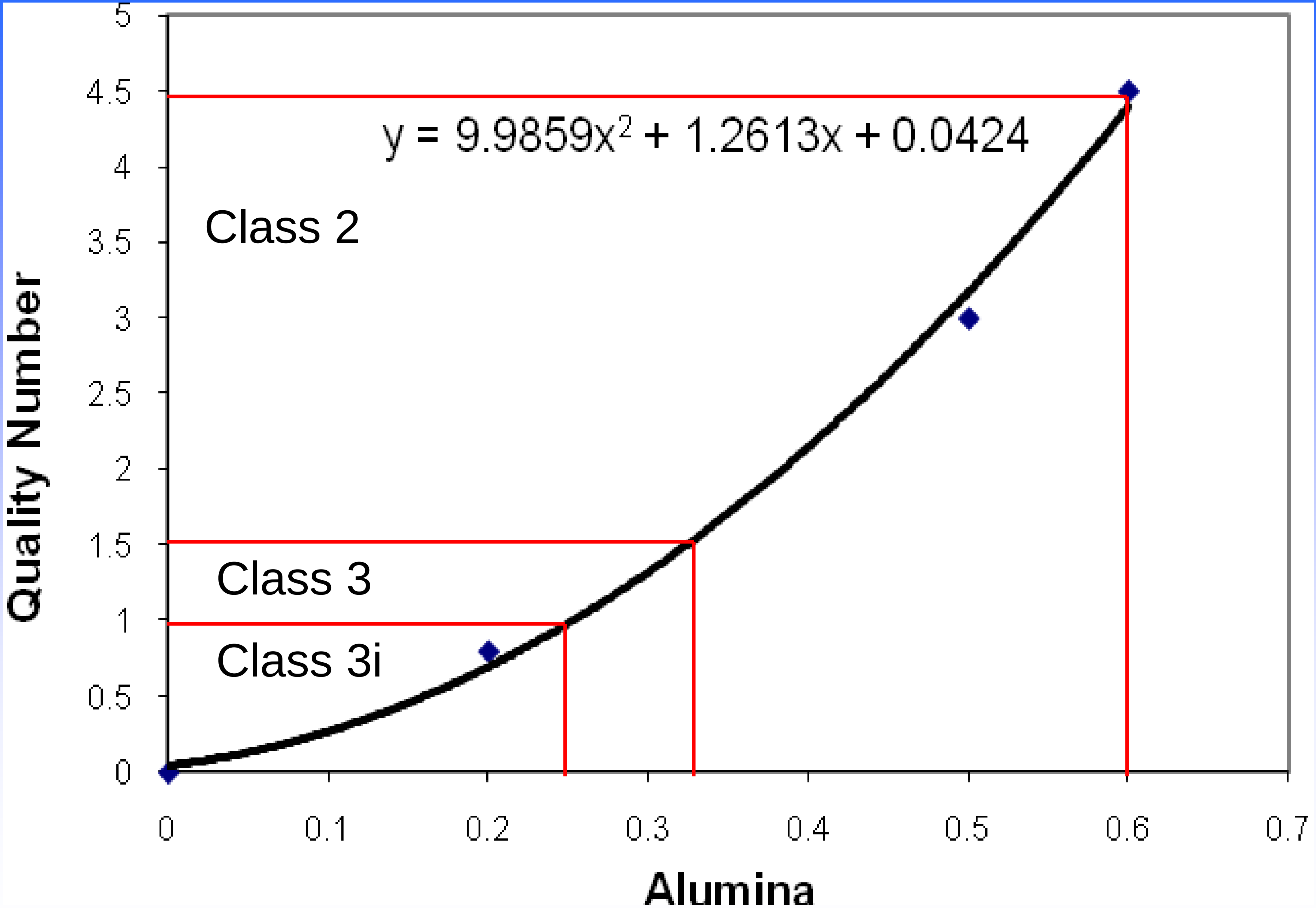
Measurement of Aluminum Oxide

- Clays are the only mineral containing alumina in limestone and dolomite (for the most part).
- Al_2O_3 as determined by XRF is an excellent way to measure clay in carbonate aggregates.
- Aggregates with elevated clay content are associated with early deterioration of PCCP concrete.

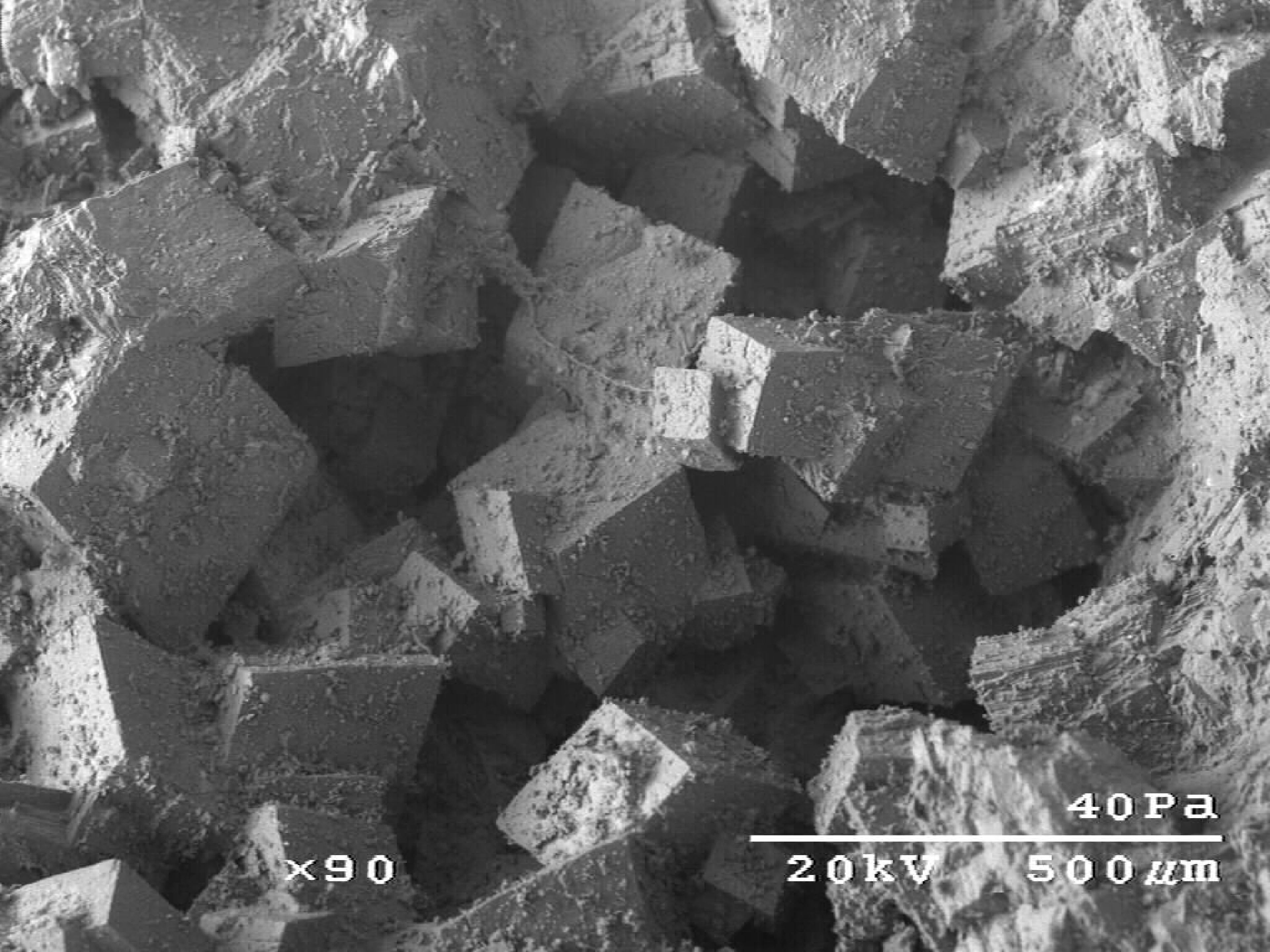
Measurement of Clay by Alumina

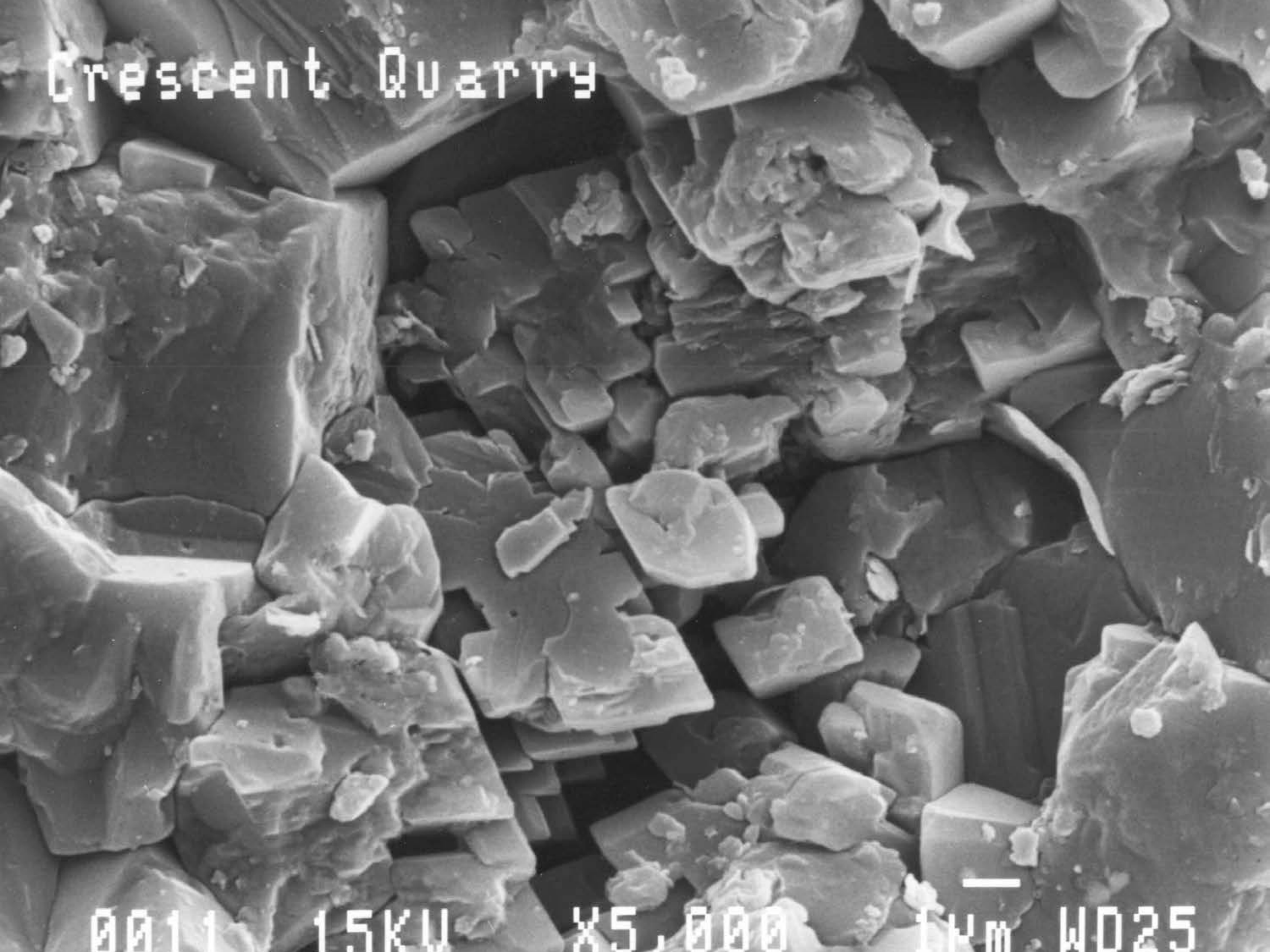



y = 9.9859x2 + 1.2613x + 0.0424
Quality Number
Alumina
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7


y = 9.9859x2 + 1.2613x + 0.0424
Class 2
Class 3
Class 3i
Quality Number
Alumina
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

Determination of the Pore System of an Aggregate


40Pa
×90
20kV
500μm


Crescent Quarry
0011 15KV X5,000 1μm WD25

Pore Index Equipment

- Used to evaluate the pore system of the aggregate.
- The test uses 4500 grams of ½ x ¾ inch material in a air tight vessel filled with water.
- The vessel is pressurized to 35 psi to force water into the pore system.
- Readings are taken at one minute to determine the large pore system (primary load) and 15 minutes to determine the small capillary size pores (secondary load).


Pore
Index

Pore Index Quality Number

- To calculate the pore index quality number, the secondary load number is adjusted to a range in which:
- Secondary of 20 = pore quality of 1
- Secondary of 25 = pore quality of 1.5
- Secondary of 30 = pore quality of 4.5

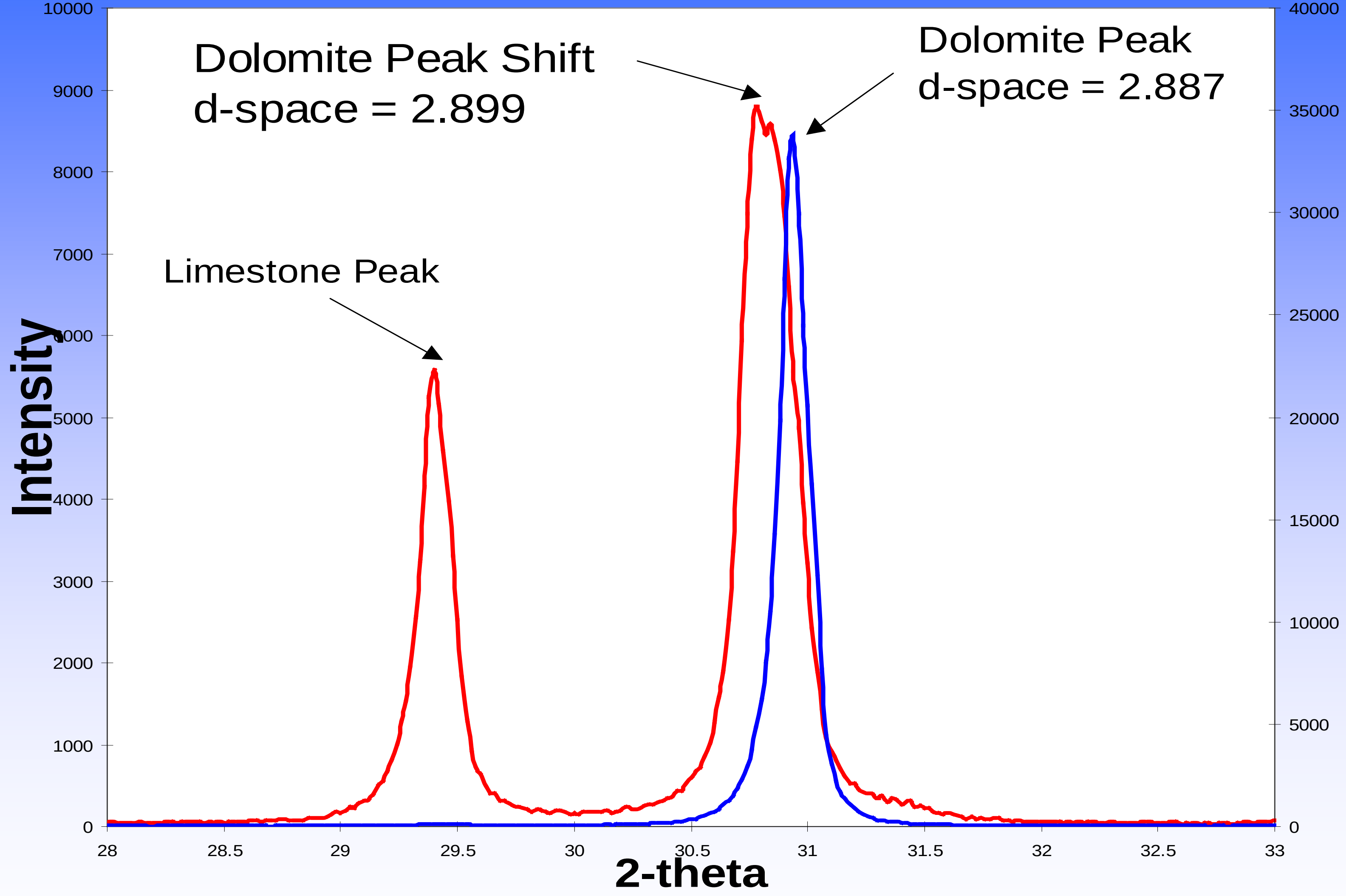
Determination of the XRF/XRD Quality Number of an Aggregate

X-Ray Diffraction (XRD)

- Is used to determine the mineral composition of a material based on the spacing of atoms in the rock.
- This method can also be used to determine the purity of dolomite crystals.


CAUTION

Dolomite Peak Shift



Dolomite Quality

- Dolomite quality is determined by XRD peak shifts of 2.900 or greater.
- The greater the peak shift the lower the quality (less stable) the dolomite mineralogy.
- Elevated sulfur levels resulting from microcrystalline pyrite (FeS_2) are extremely significant in aggregates with high dolomite fraction percents. The more sulfur the lower the quality.

Dolomite Quality

- Elevated levels of manganese correlates with poor performance.
- It is not known if manganese itself is a factor or is associated with something else that influences performance, particularly if deicing salts are used.
- XRD shift, manganese, and sulfur determine the dolomite quality number.

Limestone Quality ($CaCO_3$)

- Elevated levels of Strontium correlate with poor performance.
- In mixed limestone and dolomite aggregates, the quality number is based on the relative weight percent of each.

Overall Quality Number

- The “overall” Salt-susceptibility quality number is a combination of the three individual quality numbers.
- The combination is not based on straight percentages but rather on how dolomitic the aggregate is.
- The principal for this is based on the observation that more deterioration occurs in intermediate dolomites.

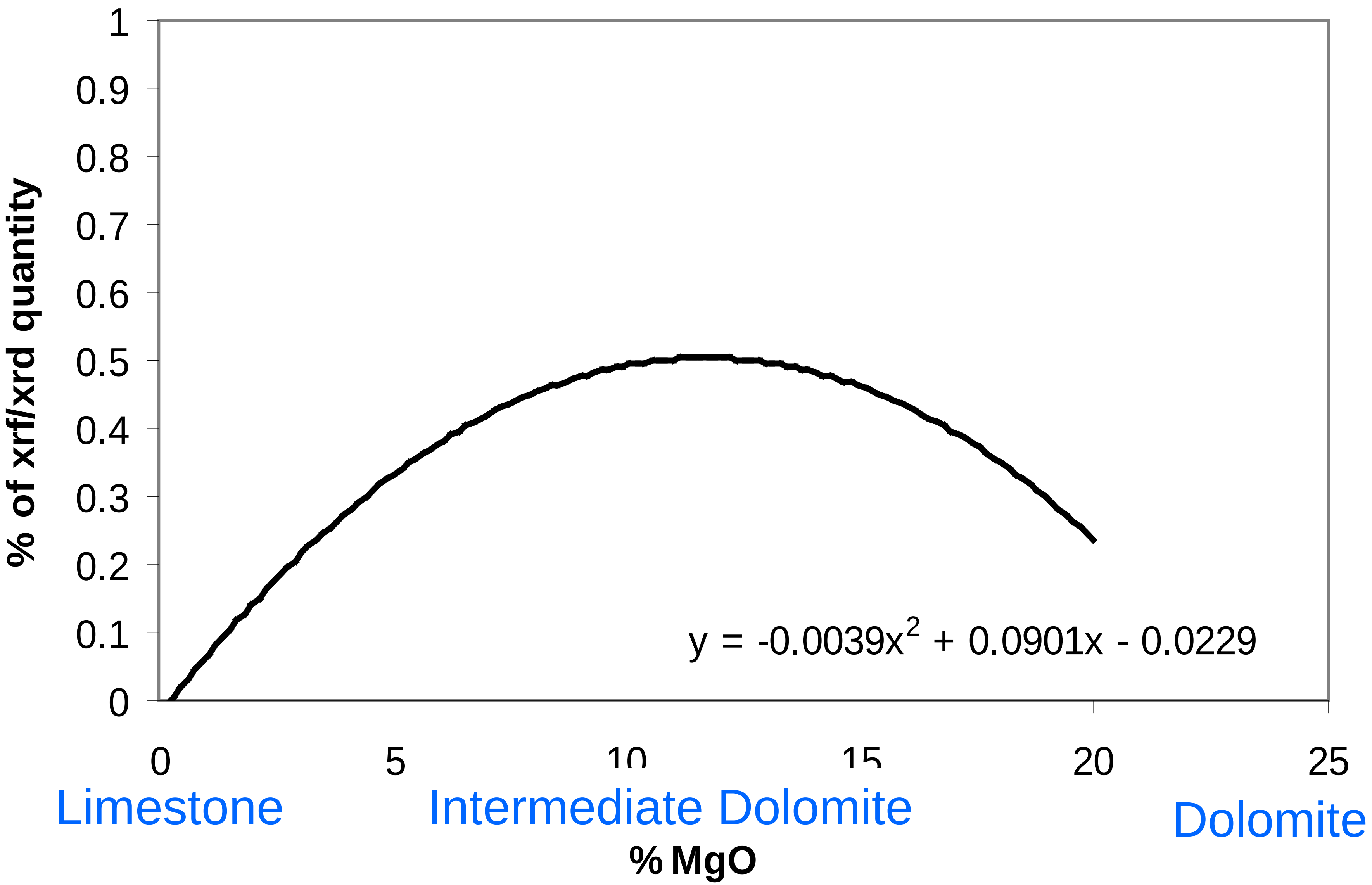
Overall Quality Number

- Pure “end member” limestones and dolomites tend to be more stable in the presence of deicing salts.
- So for pure limestones, chemistry is not as important as pore system and clay content.
- For intermediate dolomites chemistry is very important.
- For pure dolomites, all three factors are important.

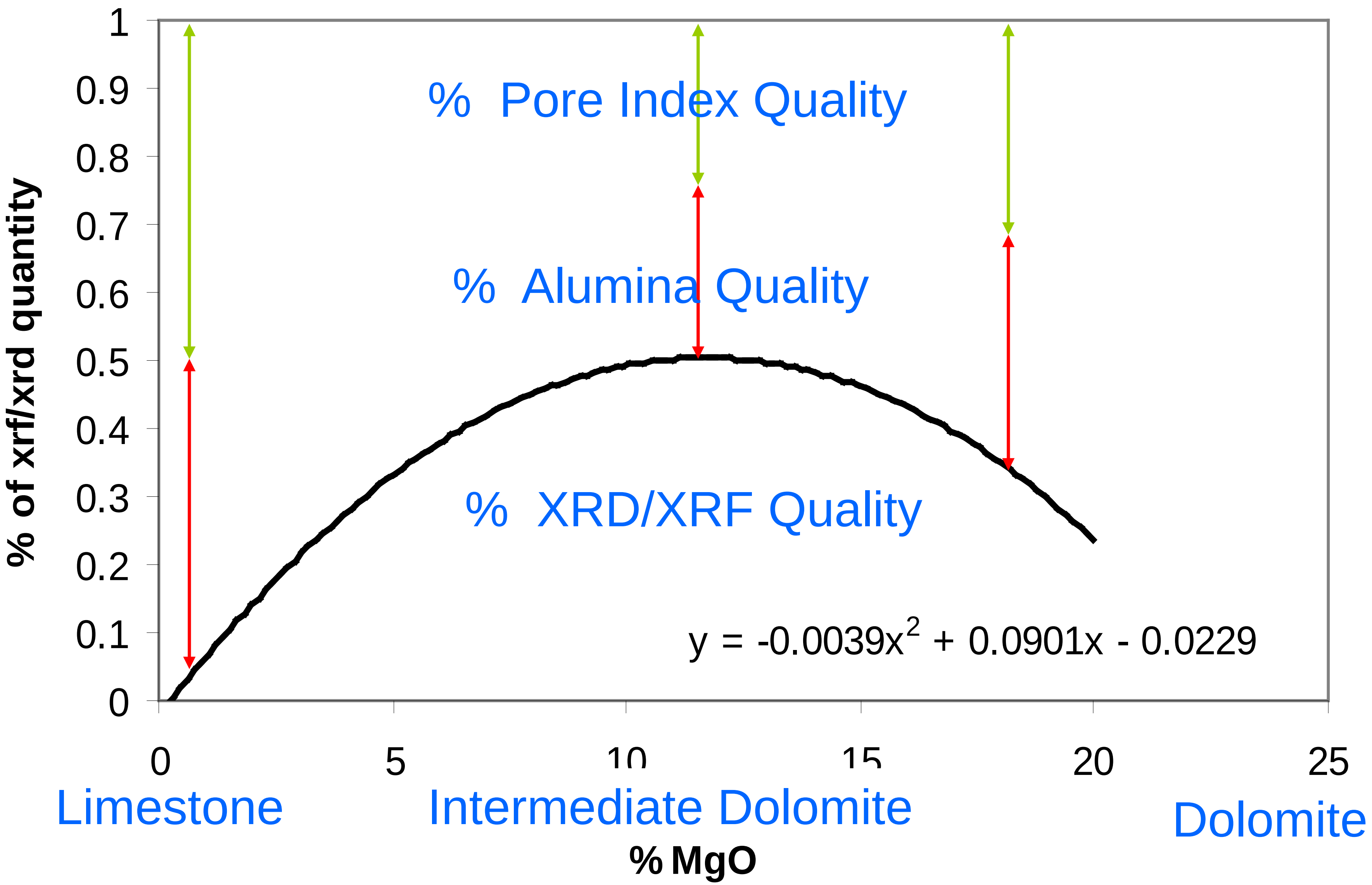
Overall Quality Number

- So for pure limestones are evaluated based on 50-50 pore index and alumina qualities.
- Intermediate dolomites are evaluated on 50% XRF-XRD, 25% pore index and 25% alumina quality.
- For pure dolomites, all three factors are important and are evaluated 1/3-1/3-1/3.
- This is done by “defining” the % of XRF/XRD for the Overall Quality Number.

Overall Quality Number



Overall Quality Number



Summary

- Aluminum oxide is a good indicator of the clay content of an aggregate. Clay content is associated with poor service histories of aggregate.
- Characterization of chemical impurities, mineral structure, and pore systems can be used to characterize aggregate performance in PCC and predict the service history of the pavement.

Conclusions

- Better characterization of most gravels.
- Better characterization of certain dolomites.
- For many sources numbers between the two test methods were comparable.
- Resolved false high Manganese quality numbers due to dendrites in gravels.
- Resolved some problems with non-clay alumina-rich minerals (extreme southeast Iowa).
- Improved correlation with pavement service history.

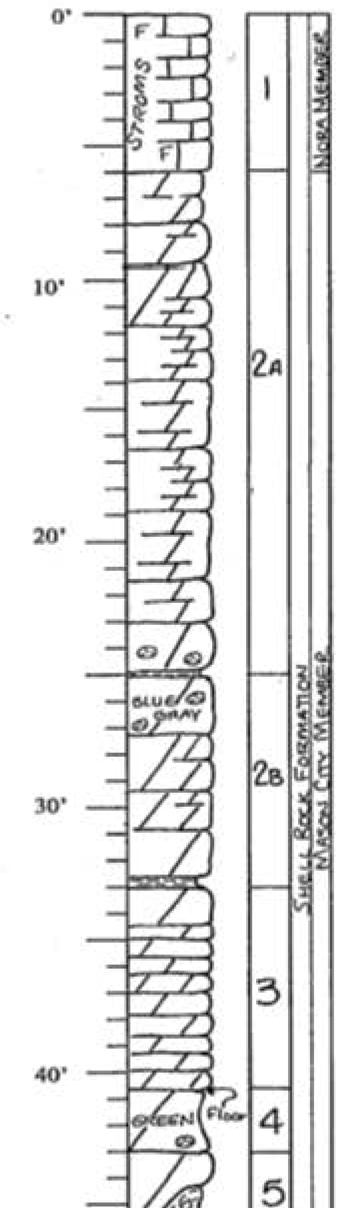
Conclusions

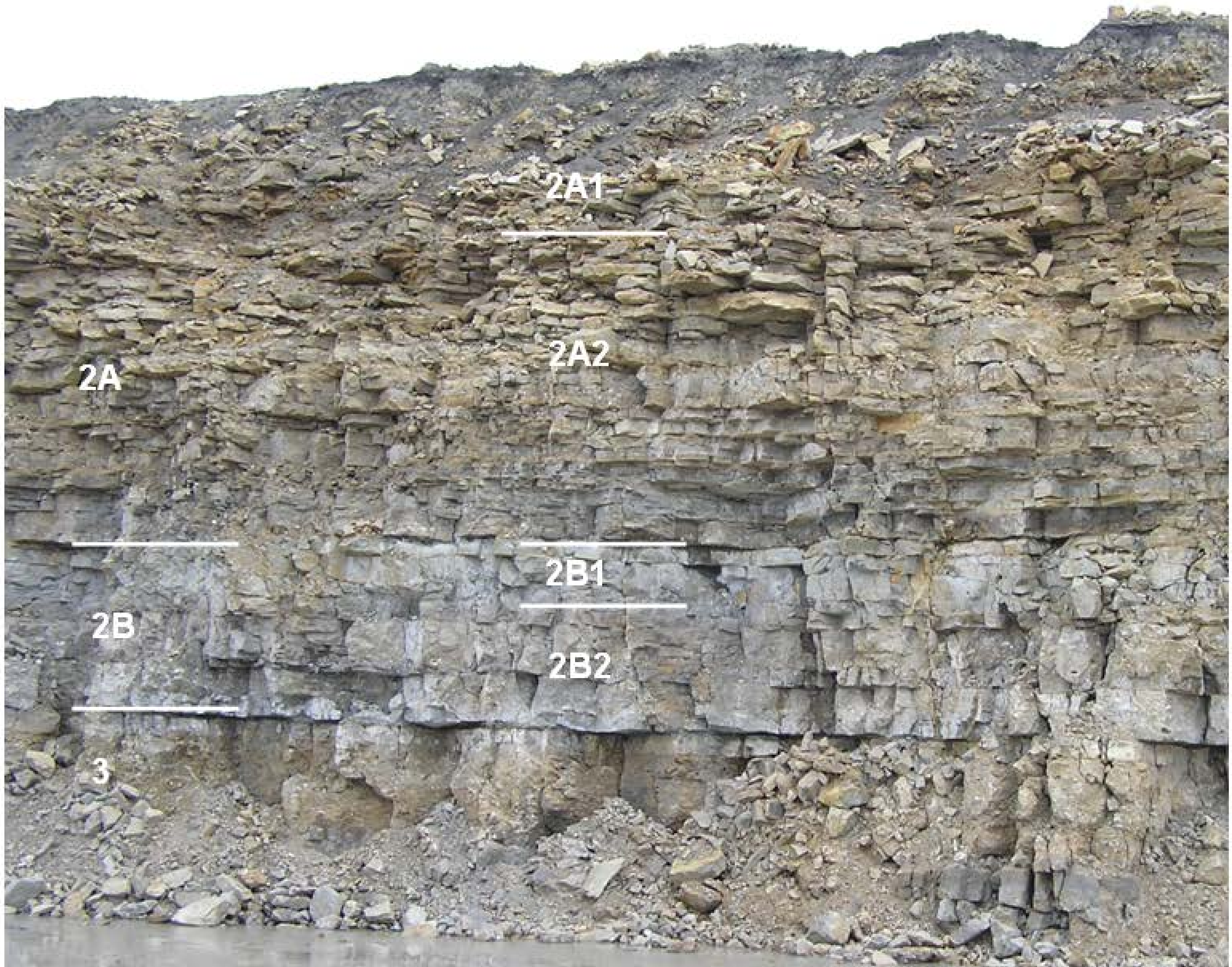
- For the carbonate rocks of Iowa, the quality number system is a fast and affective way to predict the performance and service history of aggregates.
- Test results are still actively compared to actual pavement performance.

Other reasons for the success of this Method

- Iowa practices ledge control, meaning individual beds within a quarry are evaluated.

Quarry/Owner: Trenhaile Quarry / Falkstone LLC
Remarks: Correlated to Gossman 4/13/05 after Michael 9/24/63 and Dirks & Isenberger 11/2/66; Dawson 6/13/2008; May 15, 2014
Revision of Beds 2A and 2B: Dawson Date: August 20, 2014





Other reasons for the success of this Method

- The paving history of Iowa roadway, including aggregate source information, dates back to the early1920’s.