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How JMP® Can Help Determine the Type of Surface Collapse Over Abandoned Mines

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COVERED TOPICS

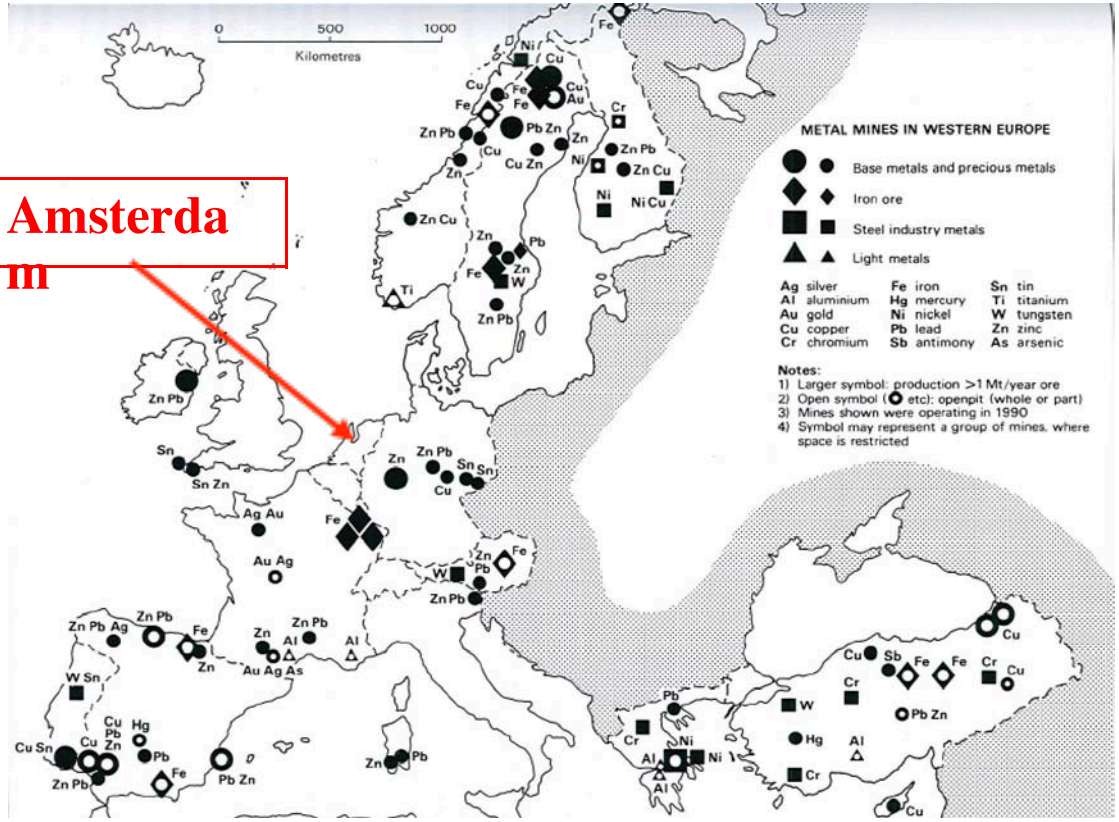
- **THE CONTEXT**
  - **Mining iron ore in France**
  - **Subsidence Phenomena**

- **STATISTICAL ANALYSIS IN THE POST MINING CONTEXT**
  - **1997: The End of mining activity**
  - **2014: 17 years after**

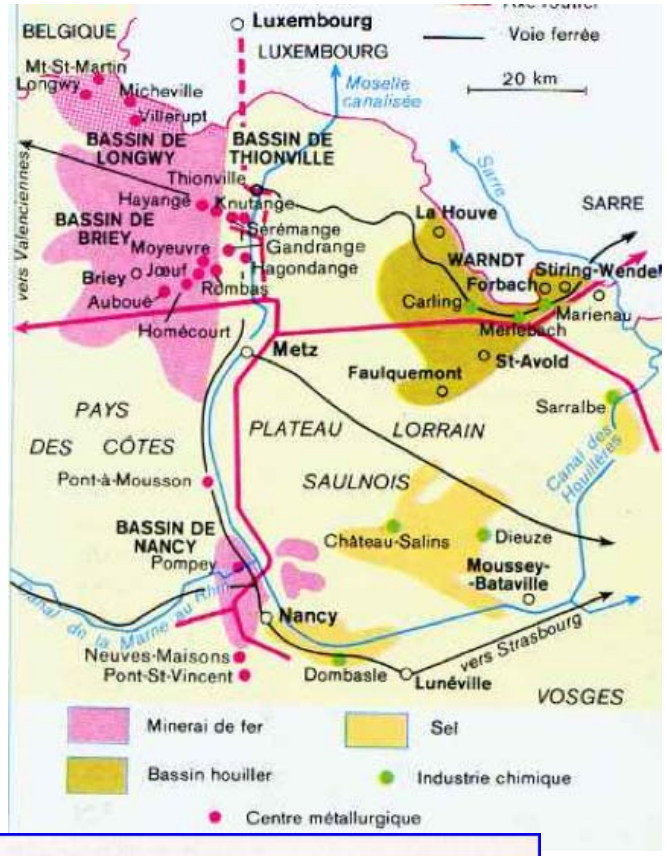
- **CONCLUSION: JMP AND STATISTICAL EXPERTISE**

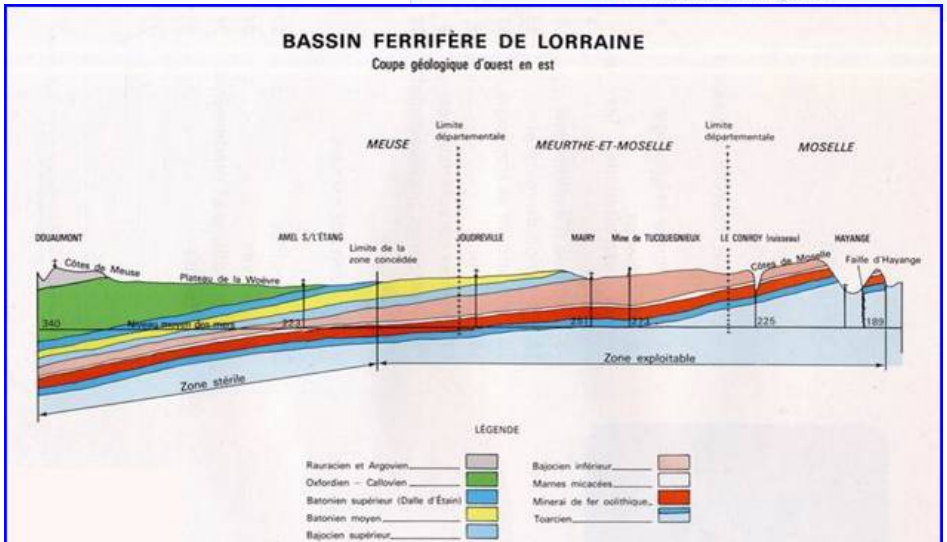
THE CONTEXT: MINING IRON ORE IN FRANCE

GEOGRAPHICAL SITUATION OF THE LORRAINE IRON ORE BASIN



GEOGRAPHICAL SITUATION OF THE LORRAINE IRON ORE BASIN

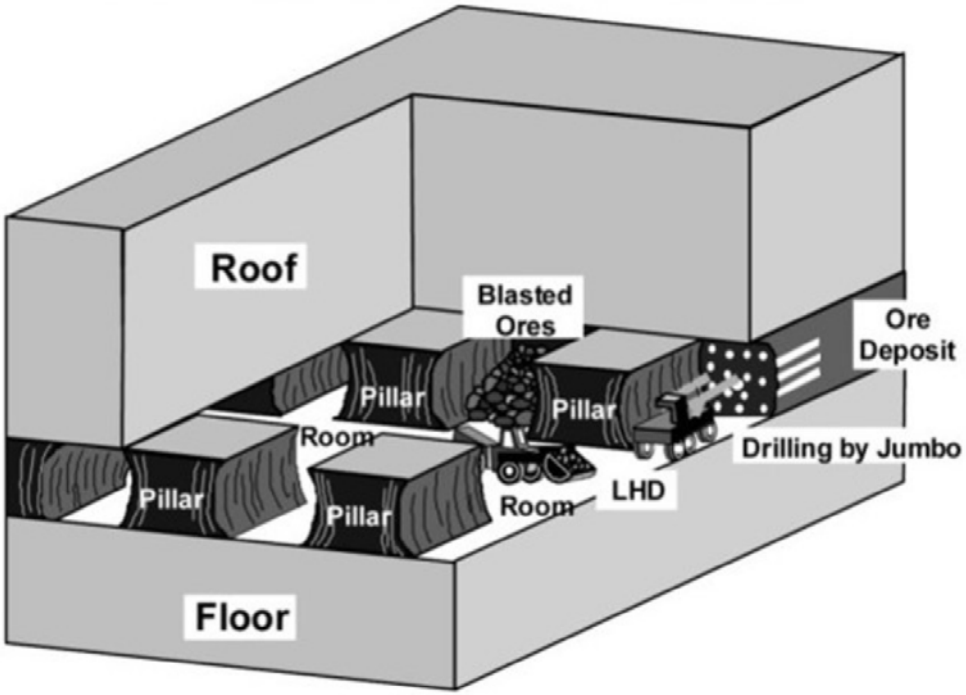


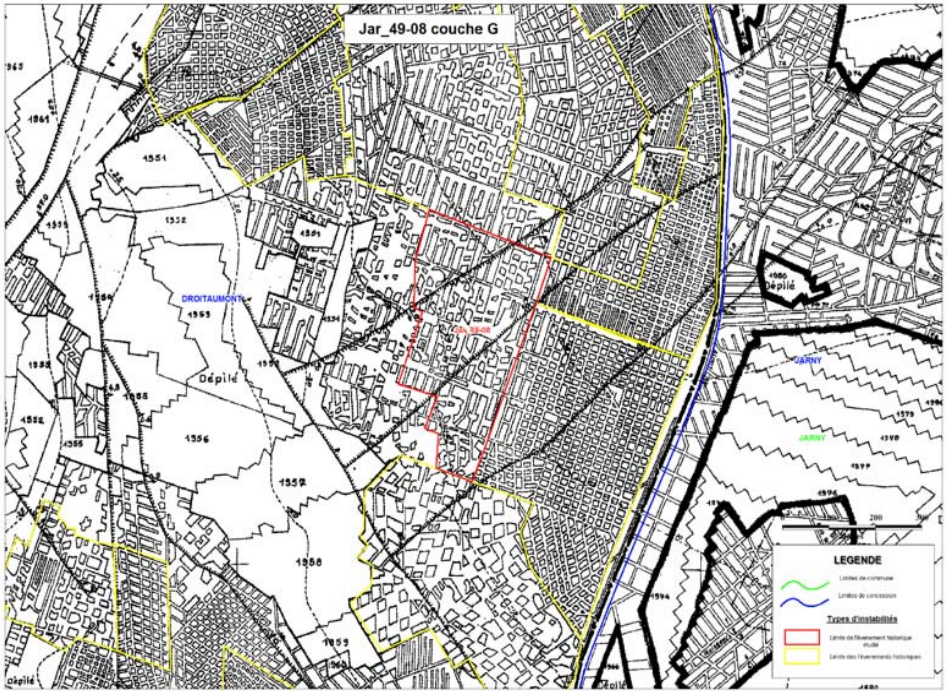


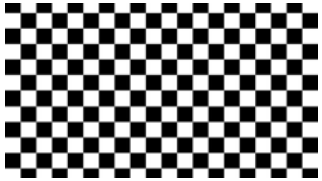
Some Data:

- **1 700 square kilometers**
- **3x109 tons worked out from 1856 to 1997**
- **3x109 m3 void volume**
- **40 000 km of galleries**

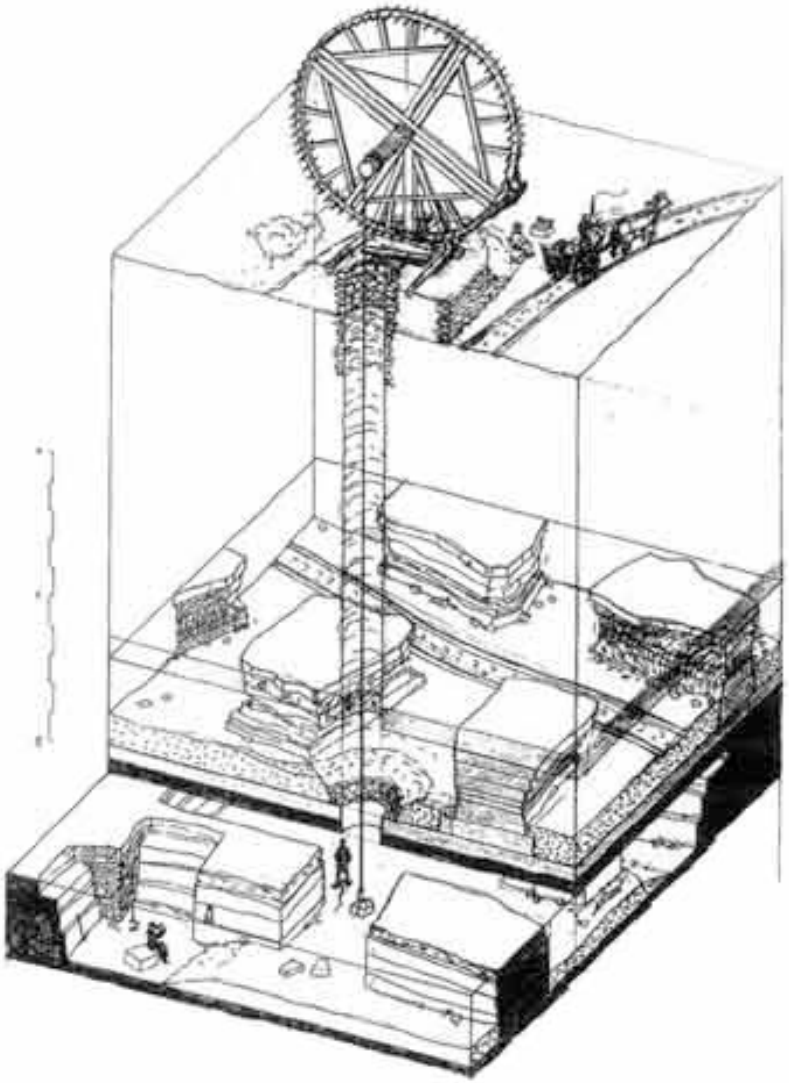
ROOM AND PILLAR MINING







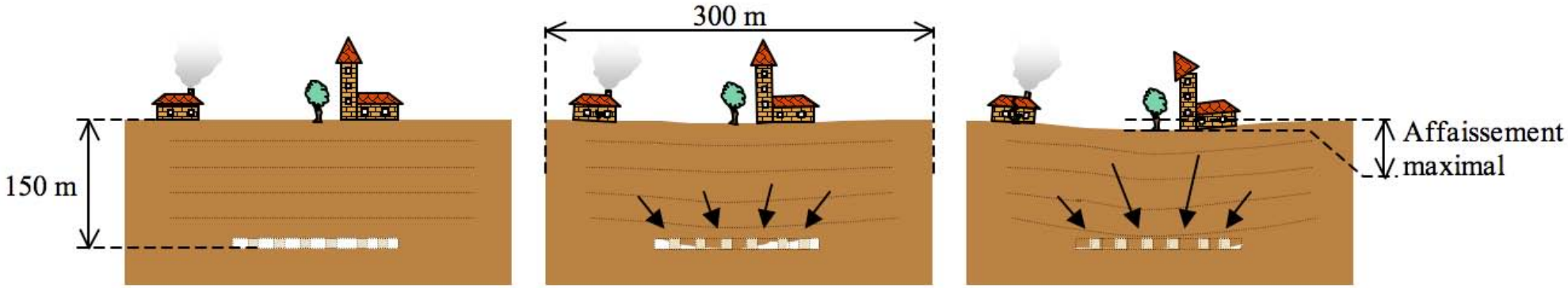
ROOM AND PILLAR MINING IN AN OLD MINE…

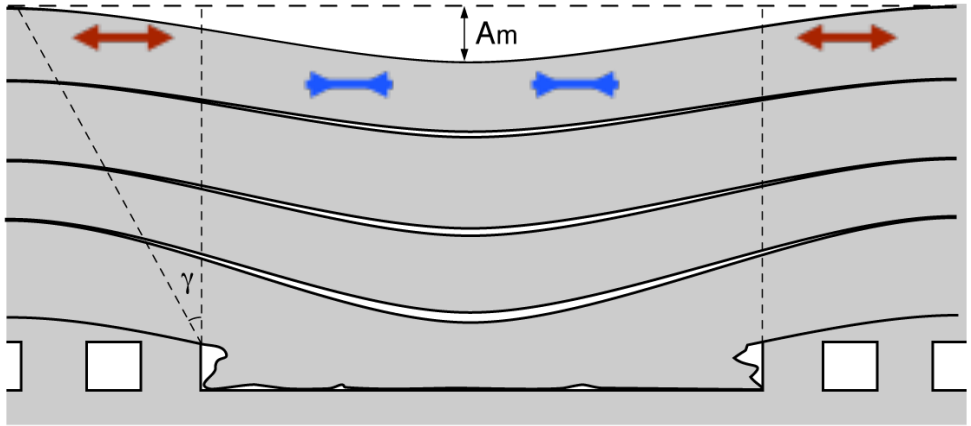


SUBSIDENCE PHENOMENA

- **PROGRESSIVE COLLAPSES**
- **BRUTAL COLLAPSES**
- **(SINKHOLES)**

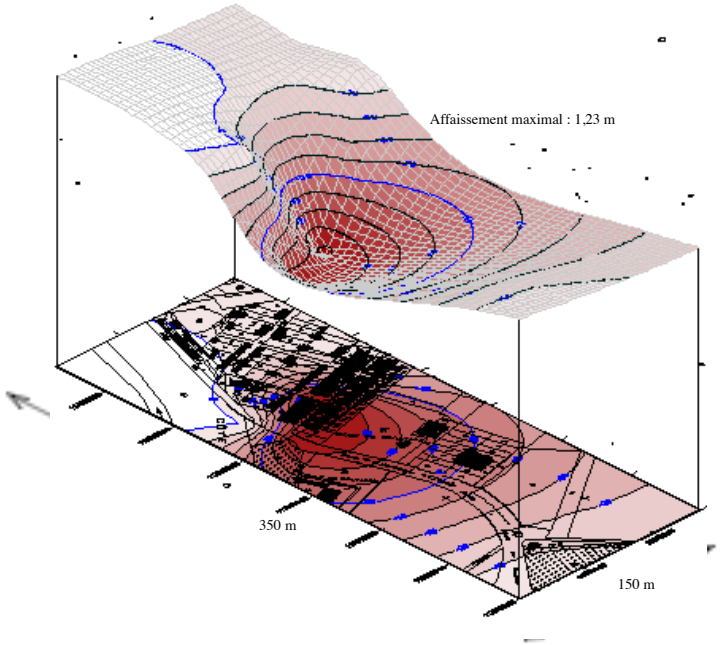
PROGRESSIVE COLLAPSE: SUBSIDENCE

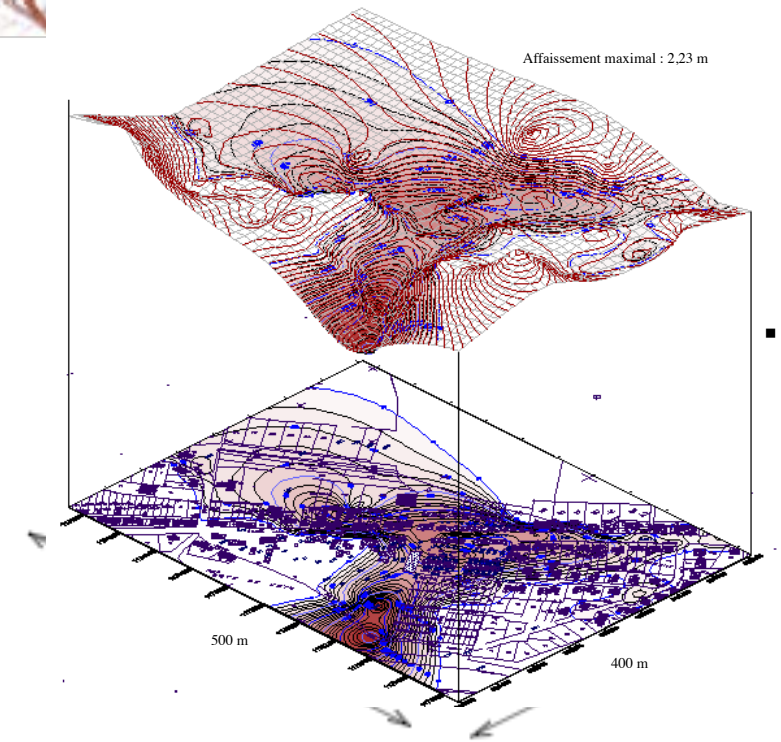




Affaissement minier

Source : INERIS





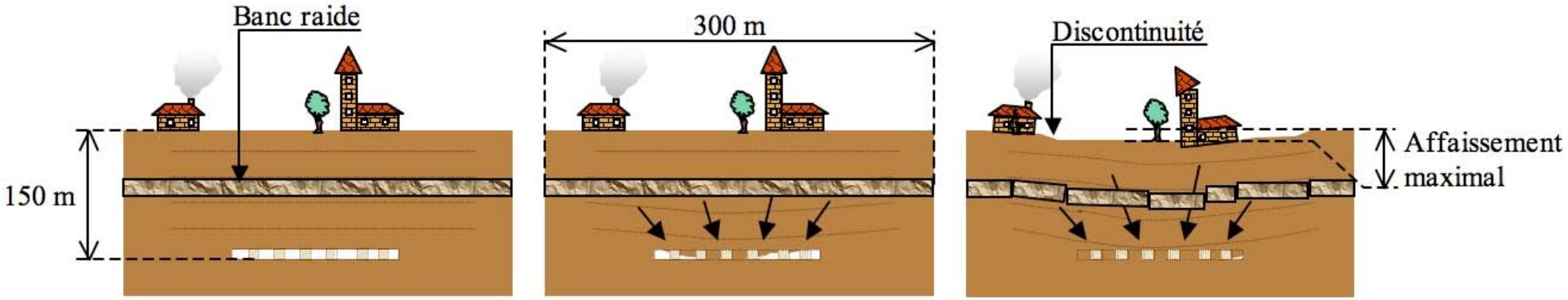
AUBOUE (Cité Coinville)

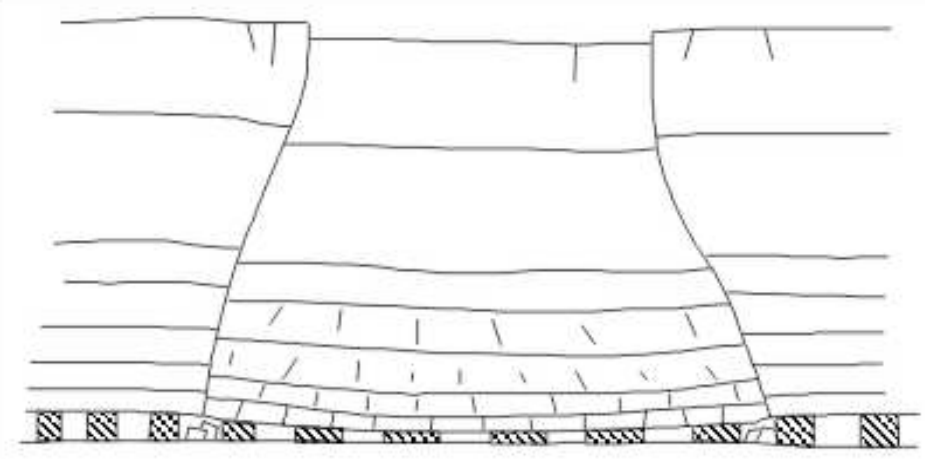
AUBOUE (Rue de Metz)

50
40
30
20
10
5
2

50
40
30
20
10
5
2

BRUTAL COLLAPSE





Effondrement, Afrique du Sud

Source : INERIS

THE POST MINING CONTEXT:
1997 END OF MINING ACTIVITY

1997: THE END OF MINING ACTIVITY

- **With the end of mining activity and the sale of miners' dwellings, the question of subsidence, hitherto an industrial hazard, became an environmental risk.**

- **The damage caused by mining, an issue previously addressed privately by the owners, became the responsibility of government services (GEODERIS) when mining concessions were handed over to the State.**

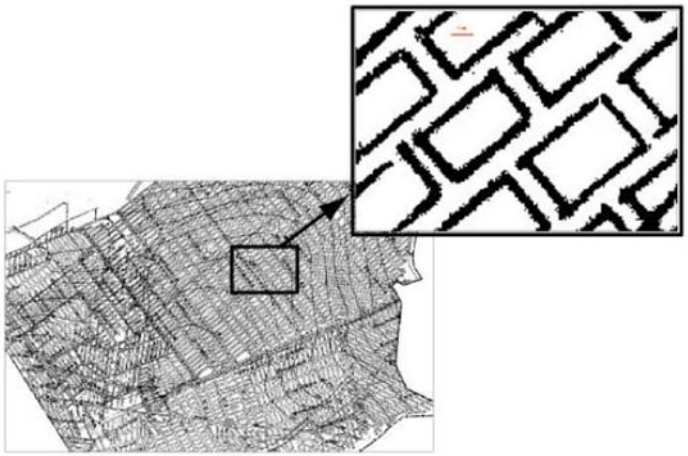
1997: THE END OF MINING ACTIVITY

- This increased concern of regional authority led GEODERIS to try to define for the basin (where geological situations are almost the same) a criterion of discrimination between situations (underground workings) where brutal collapses are likely to happen and others where progressive ones are to be expected.
- In 1998, GEODERIS experts have started with a back-analysis of the cases already happened during the 20th century and they finally selected 16 “reference” well documented accidents of unpredicted collapses in the basin:
    - 8 brutal
    - 8 progressive
- They localized and reported any geological, geotechnical, or geometrical aspects over these 16 cases.

DATA UNCERTAINTIES

- **Reliability of the mining maps**
- **Informal nature of several data (oral statements, newspaper articles, etc.)**
- **Difficulty to analyze events that occurred in the past**

Example: The determination of the nature of the uncertainty is far more difficult for the geometrical parameters such as pillar dimensions or mining depth.



At a 1:5000 scale, a pencil line thickness on the map is equivalent to more than 1m in the mine. For classical Lorraine pillars, such a map inaccuracy may lead to a 10 % error on the values used for pillar dimensions and obviously to significant errors in the risk analysis process

DATA BASE

Among the collected variables in these 16 « historical reference » subsided zones, experts have chosen 7 measured, observed, or calculated variables:

- **Width of rooms, *W_Gal* (m)**
- **Depth of the subsided zone, *H* (m)**
- **Thickness of exploited seams, *W* (m)**
- **A constant parameter characterizing whether the subsided zone is adjacent to other zones of exploitation (virgin zone, a zone adjacent to a caved zone, and a zone surrounded by caved zones), *C_surch***
- **Ratio between volume extracted and initial volume in place, *Defruit* (%)**
- **Hydraulic diameter of pillars, *Diam_hydr* (m)**
- **Maximum stress applied to pillars, *Sigma_tot* (MPa)**
- **And the type of observed collapse, *Type* (Progressive or Brutal).**

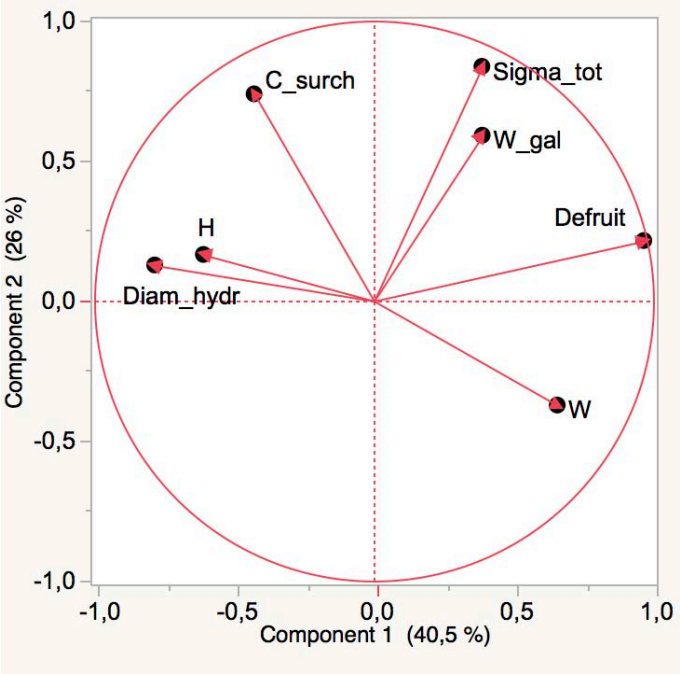
QUESTION TO THE STATISTICAL EXPERT:

HOW CAN YOU HELP DEFINE SUCH A CRITERION?

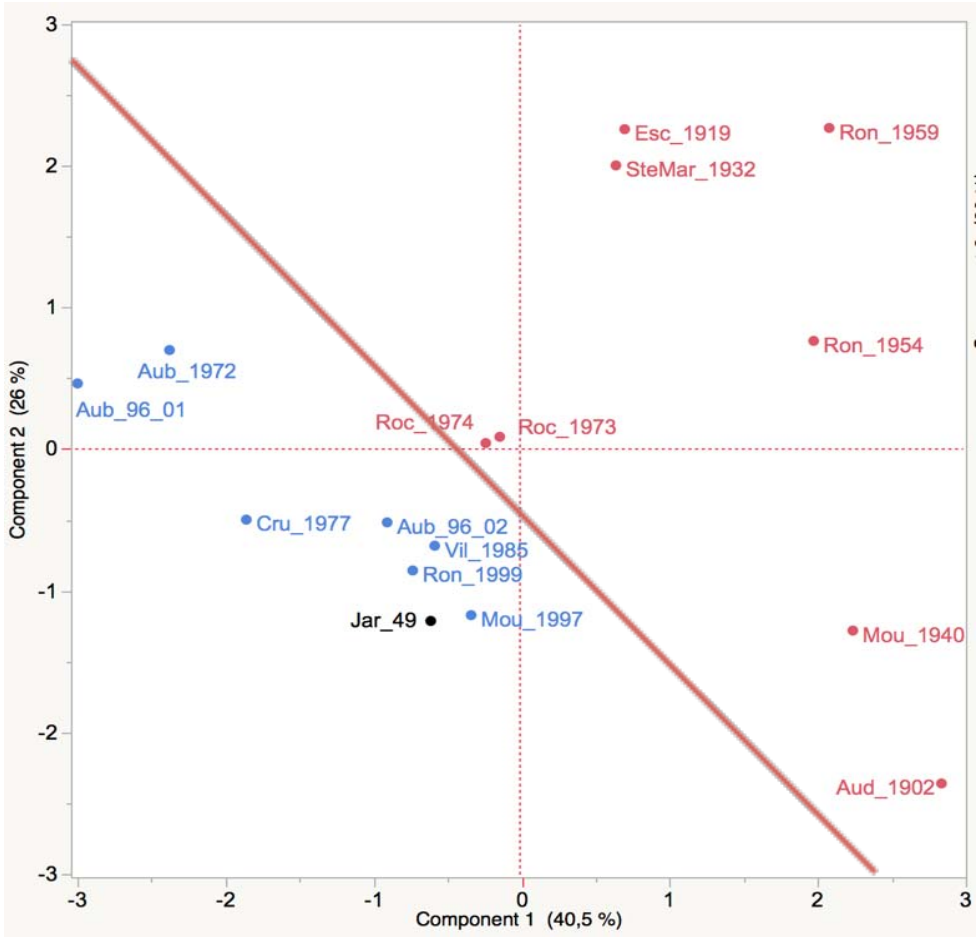
STATISTICAL DATA ANALYSIS SEVERAL JMP PLATFORMS FOR DISCRIMINATION

- DESCRIPTIVE ANALYSIS
- PRINCIPAL COMPONENT ANALYSIS
- ONEWAY ANALYSIS OF VARIANCE
- DISCRIMINANT ANALYSIS
- (PARTITION)

PRINCIPAL COMPONENTS ANALYSIS (PCA)

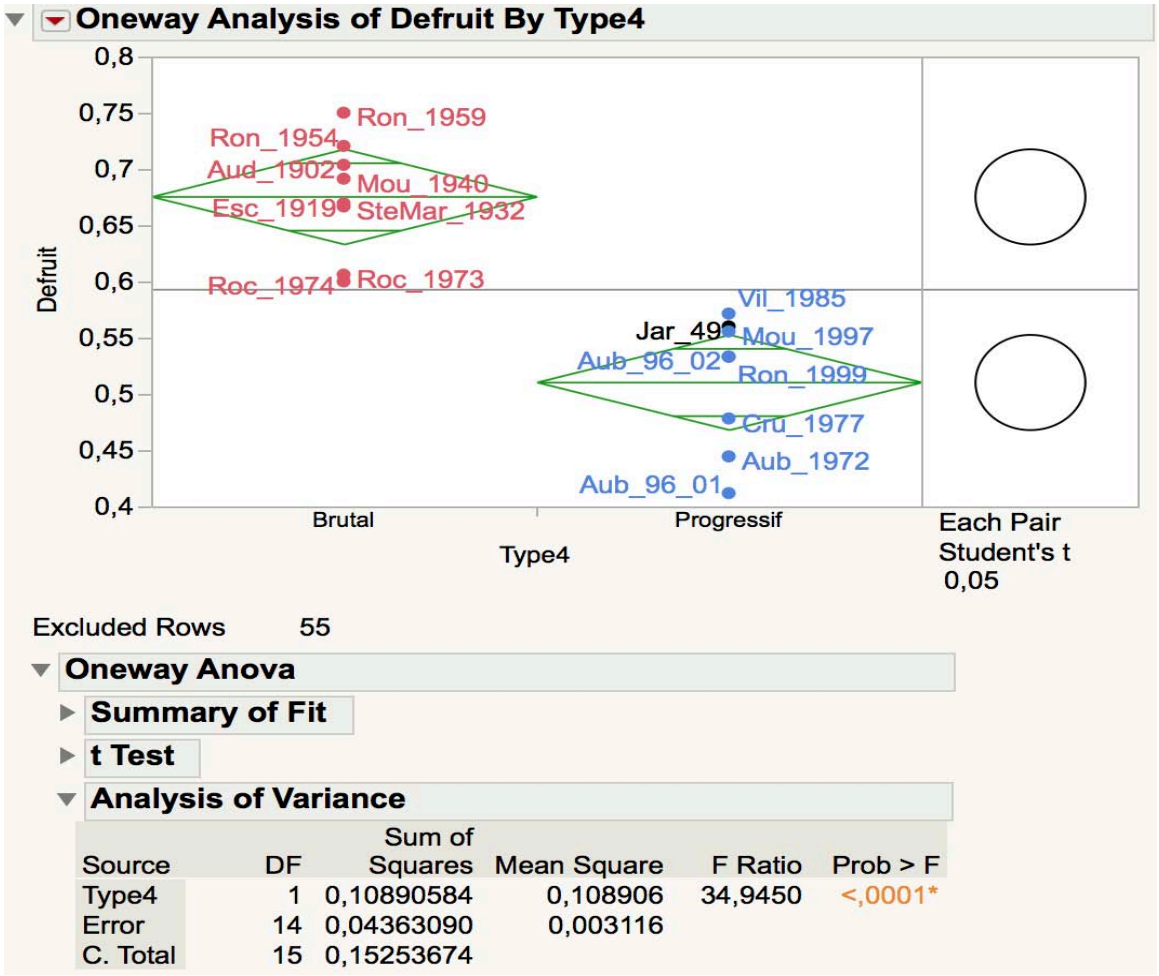


Correlation circle: Factor plot of variables over the factorial plane defined by the first two components of the factor analysis (JMP loading plot)



Projection of 16 "historical" collapses over the factorial plane 1 & 2
8 red=brutal 8 blue=progressive (JMP score plot)

ONEWAY ANALYSIS OF VARIANCE



Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Type4	1	0,10890584	0,108906	34,9450	<,0001*
Error	14	0,04363090	0,003116		
C. Total	15	0,15253674			

Oneway Analysis of *Defruit* by *Type*

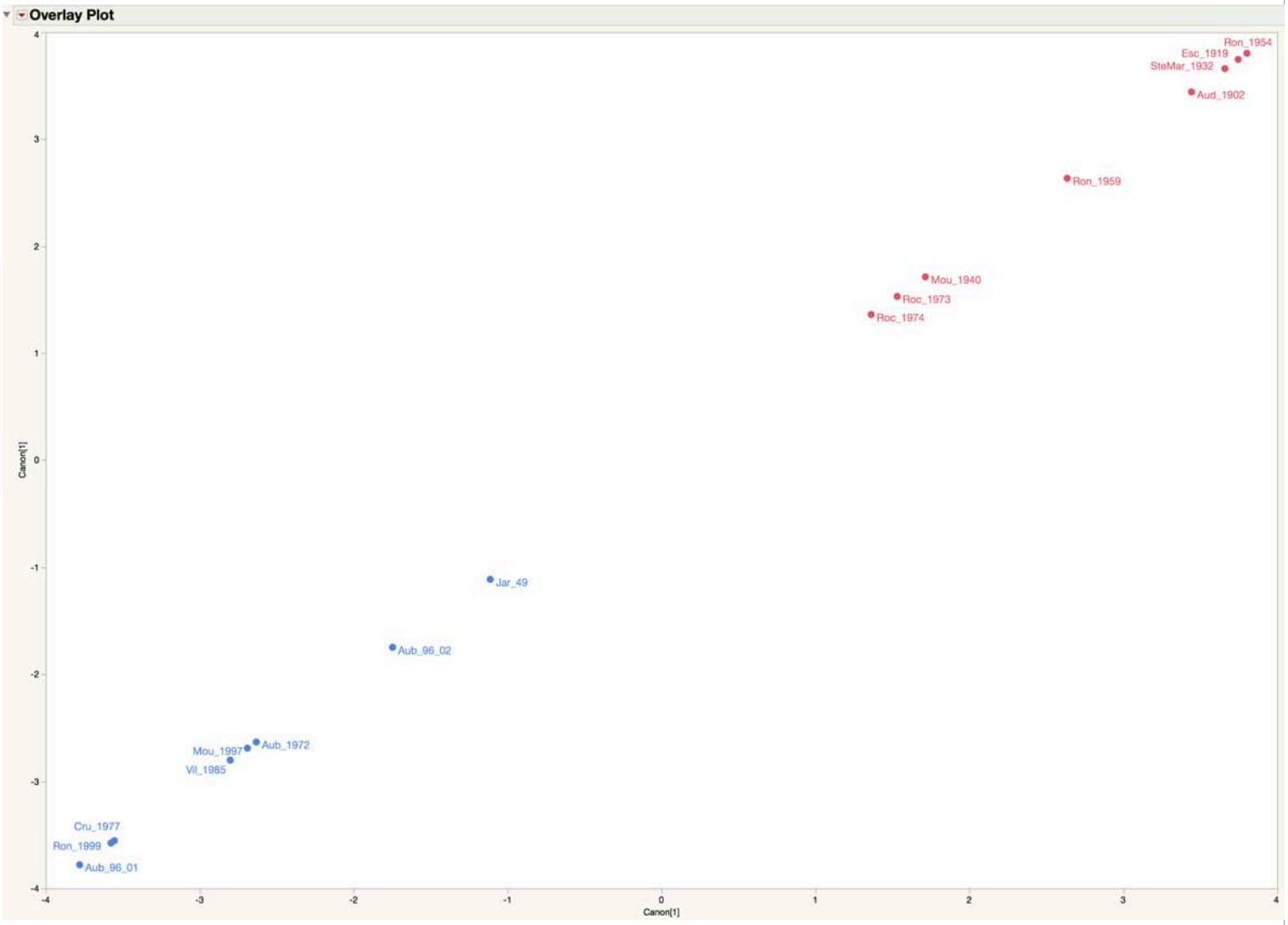
DISCRIMINANT ANALYSIS

Score Summaries

Source	Count	Number Misclassified	Percent Misclassified	Entropy RSquare	-2LogLikelihood
Training	16	0	0,00000	0,99971	0,00646

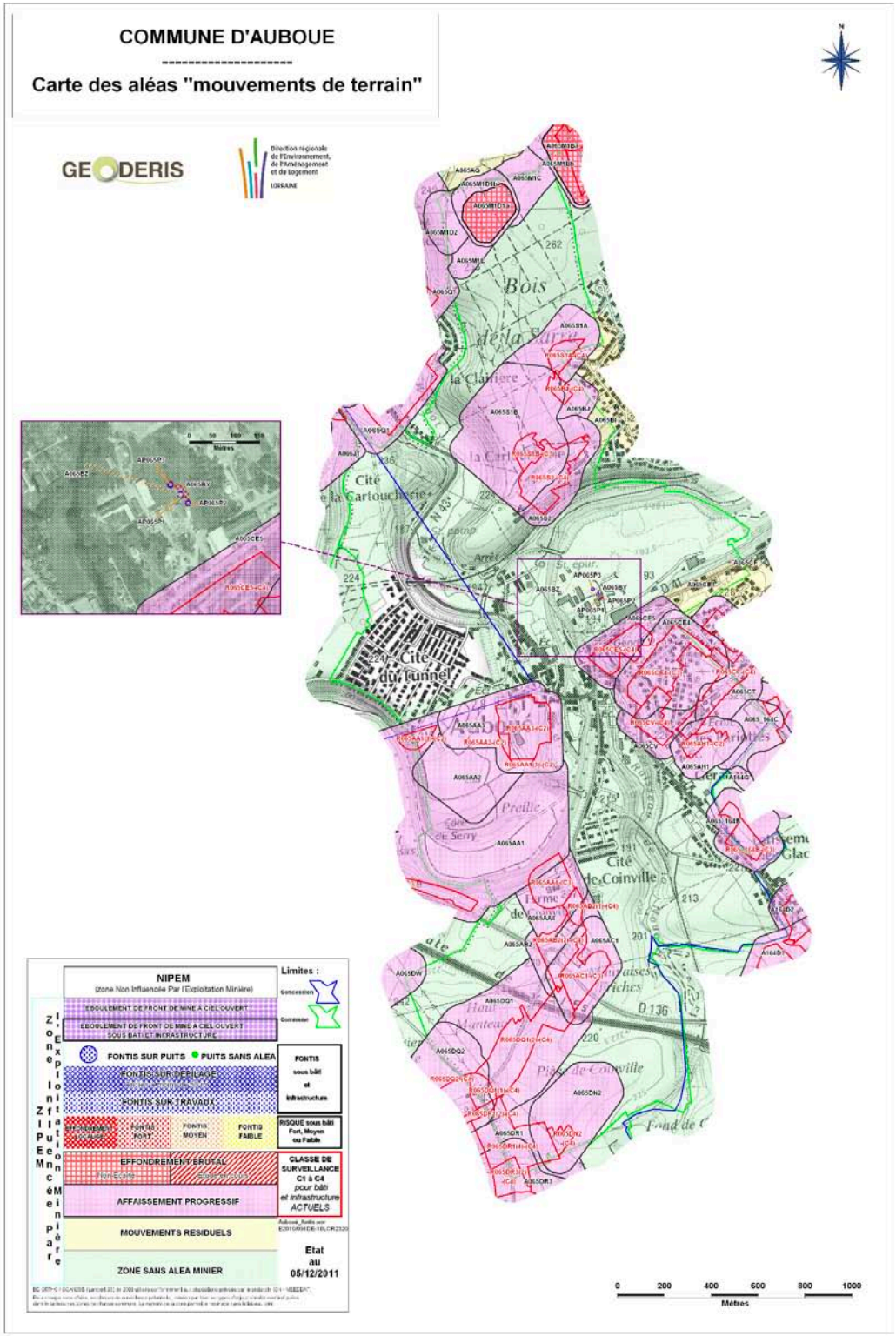
Training

Actual	Predicted Count	
Type2	Brutal	Progressive
Brutal	8	0
Progressive	0	8



16 collapses projected over the discriminant dimension

EXAMPLE OF A HAZARD ZONES MAP



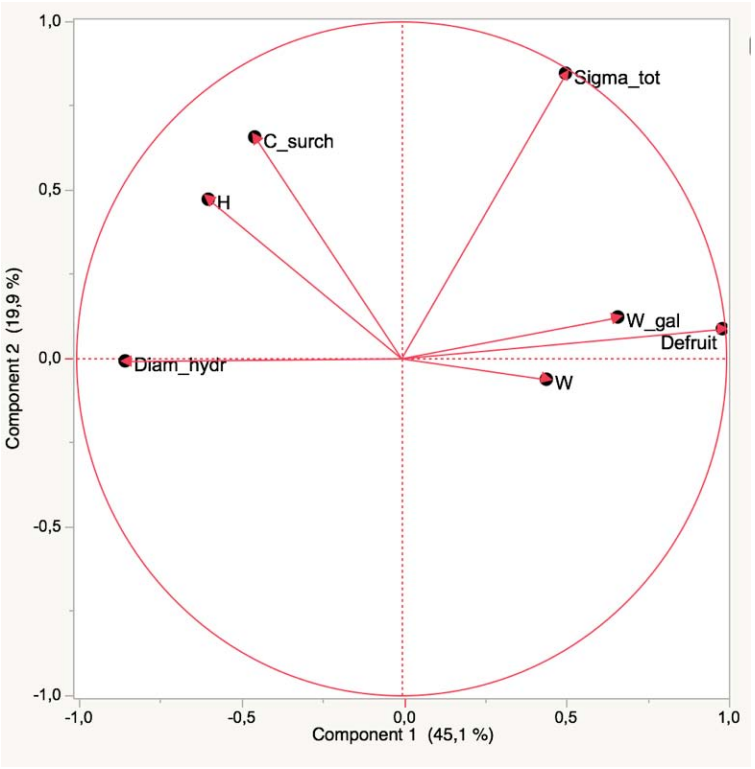
THE POST MINING CONTEXT: 2014

17 YEARS AFTER THE END OF MINING ACTIVITY

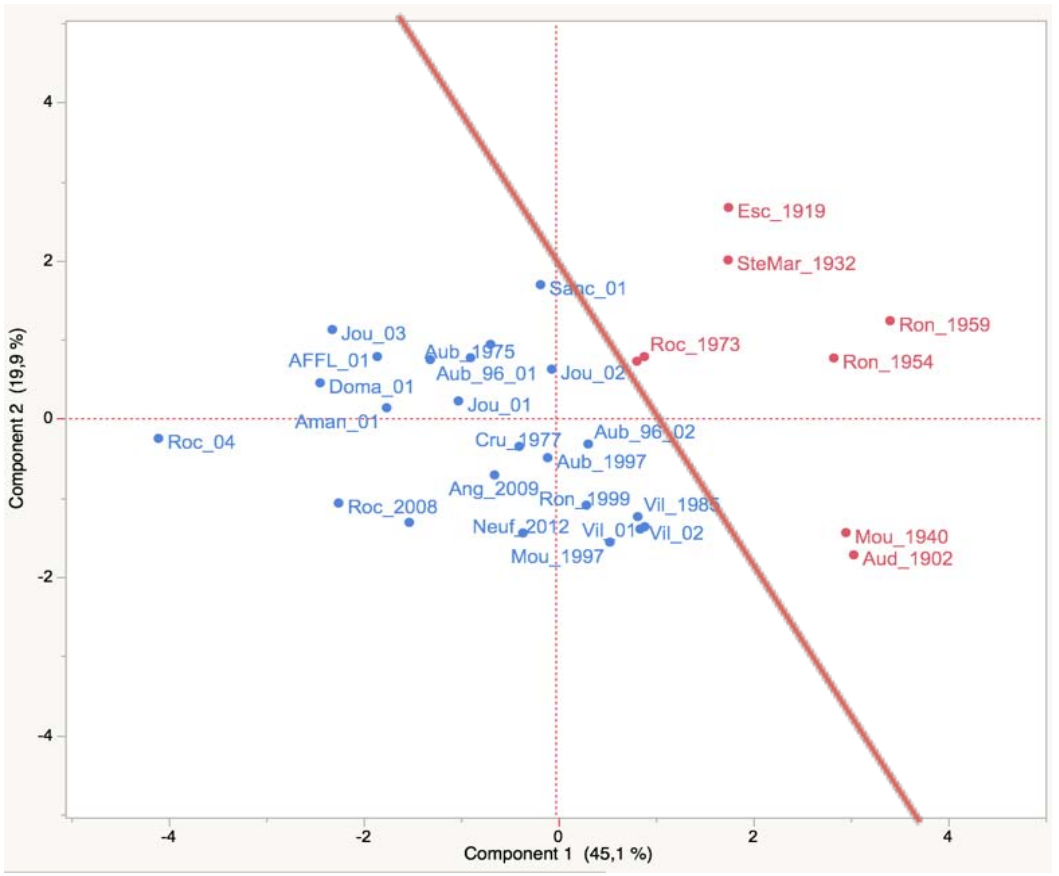
2014: 17 YEARS AFTER THE END OF MINING ACTIVITY

- Since the 1999 first study, GEODERIS experts have identified other areas where subsidence literature searches and archives have been undertaken.
- Furthermore, several of subsidence phenomena occurred in the years 2000.
- An update of the base of mining subsidence and collapse was possible.
- This research has allowed to identify 70 cases, including the 16 reference cases used up to now. But experts have only identified the type for 31 collapses: the previous 8 as brutal, and 23 as progressive. They were unable to assign a type to the other 39 collapses:
    - 8 brutal
    - 23 progressive
    - 39 unknown

PRINCIPAL COMPONENTS ANALYSIS (PCA)

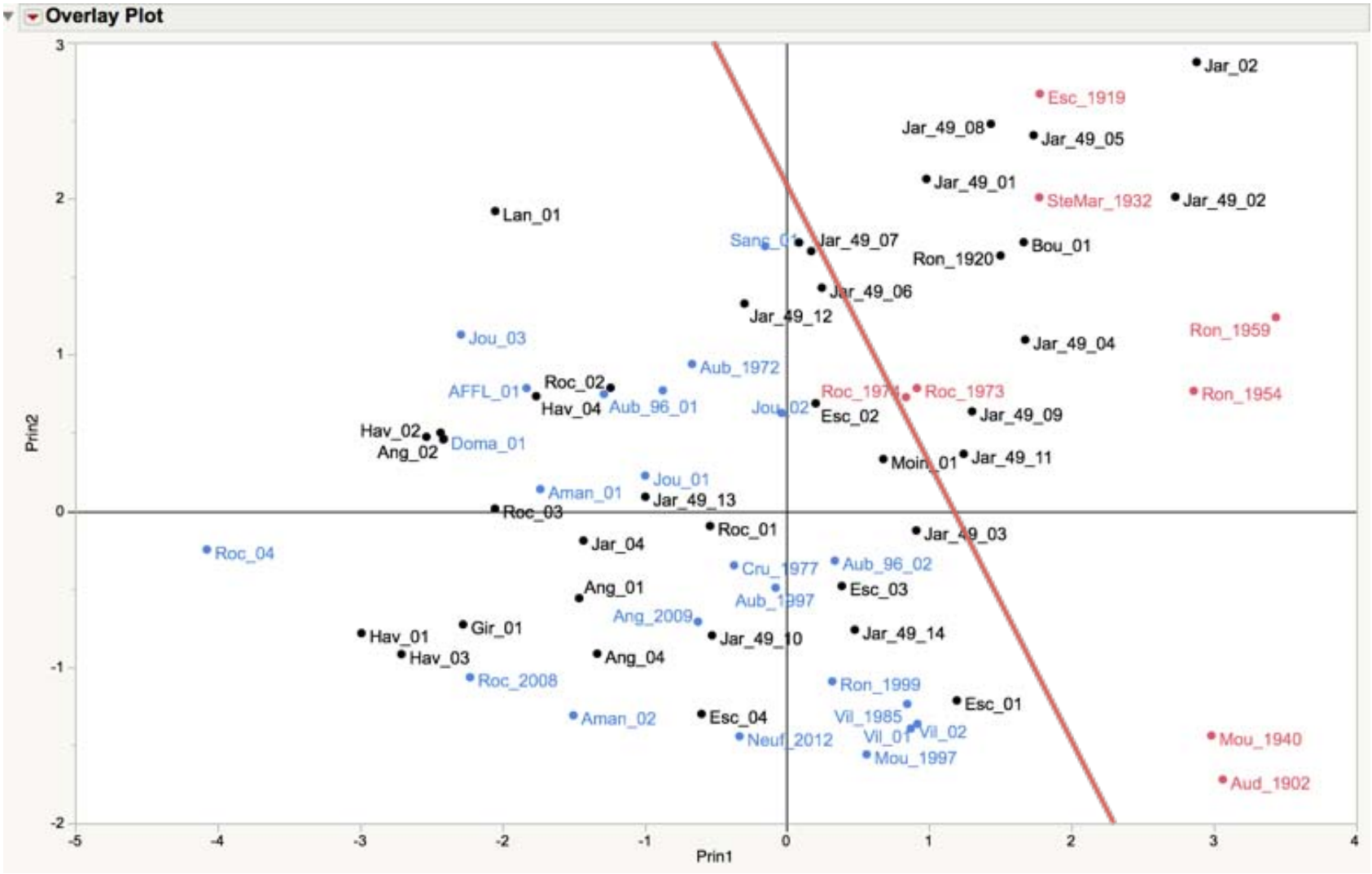


Correlation circle: Factor plot of variables over the factorial plane defined by the first two components of the factor analysis (JMP loading plot)



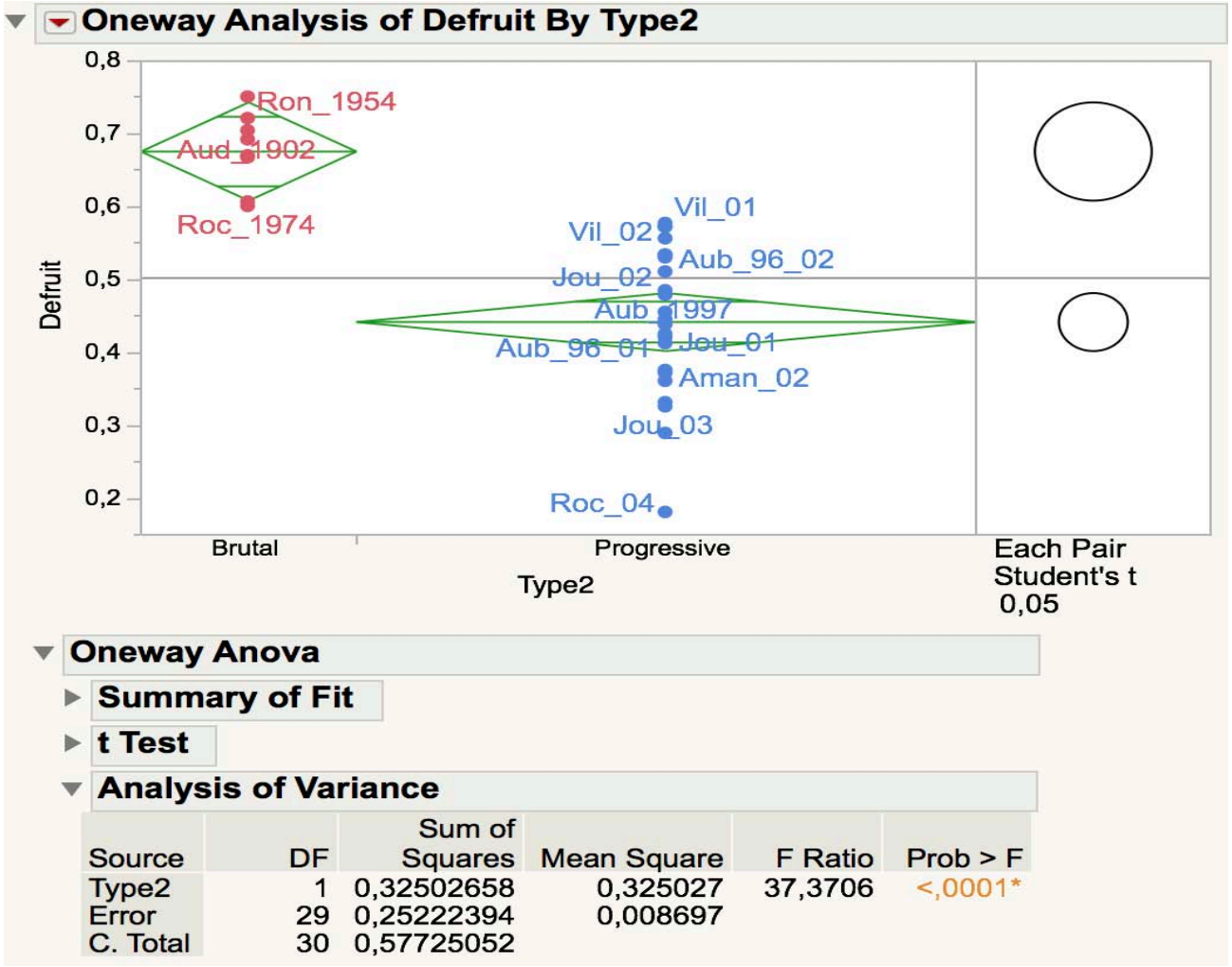
Projection of 31 known collapses over the factorial plane 1 & 2
8 red=brutal 23 blue=progressive (JMP score plot)

PRINCIPAL COMPONENTS ANALYSIS (PCA)



Projection of the 70 collapses over the factorial plane 1 & 2
8 red=brutal 23 blue=progressive 39 black=unknown (JMP score plot)

ONEWAY ANALYSIS OF VARIANCE



Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Type2	1	0,32502658	0,325027	37,3706	<,0001*
Error	29	0,25222394	0,008697		
C. Total	30	0,57725052			

Oneway Analysis of *Defruit* by *Type*

DISCRIMINANT ANALYSIS

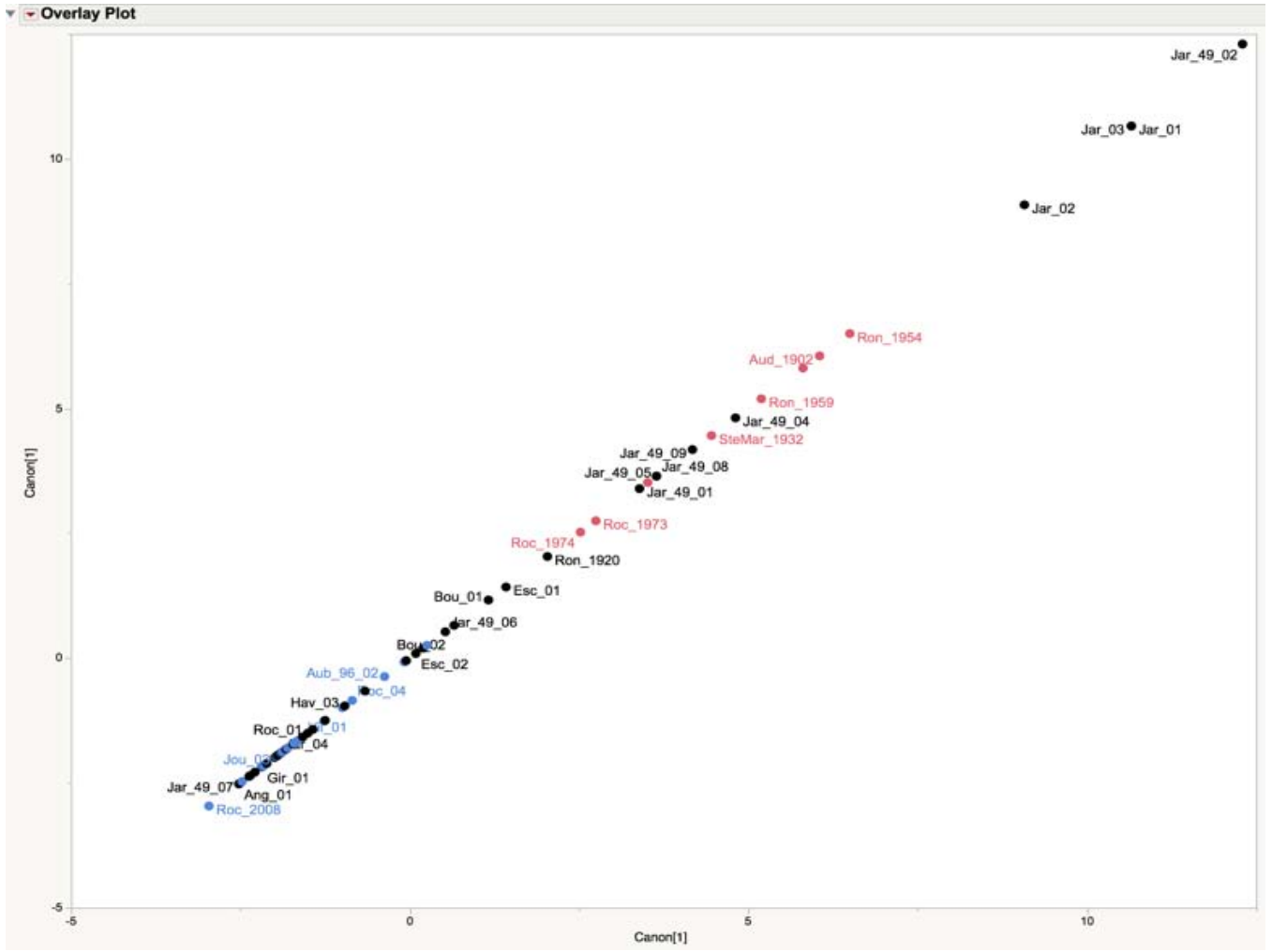
Contingency Table

Pred Type2

Type3	Count / Total % / Col % / Row %	Brutal	Progressive	Total
Brutal		8	0	8
		11,43	0,00	11,43
		44,44	0,00	
		100,00	0,00	
Progressive		0	23	23
		0,00	32,86	32,86
		0,00	44,23	
		0,00	100,00	
Unknown		10	29	39
		14,29	41,43	55,71
		55,56	55,77	
		25,64	74,36	
Total		18	52	70
		25,71	74,29	

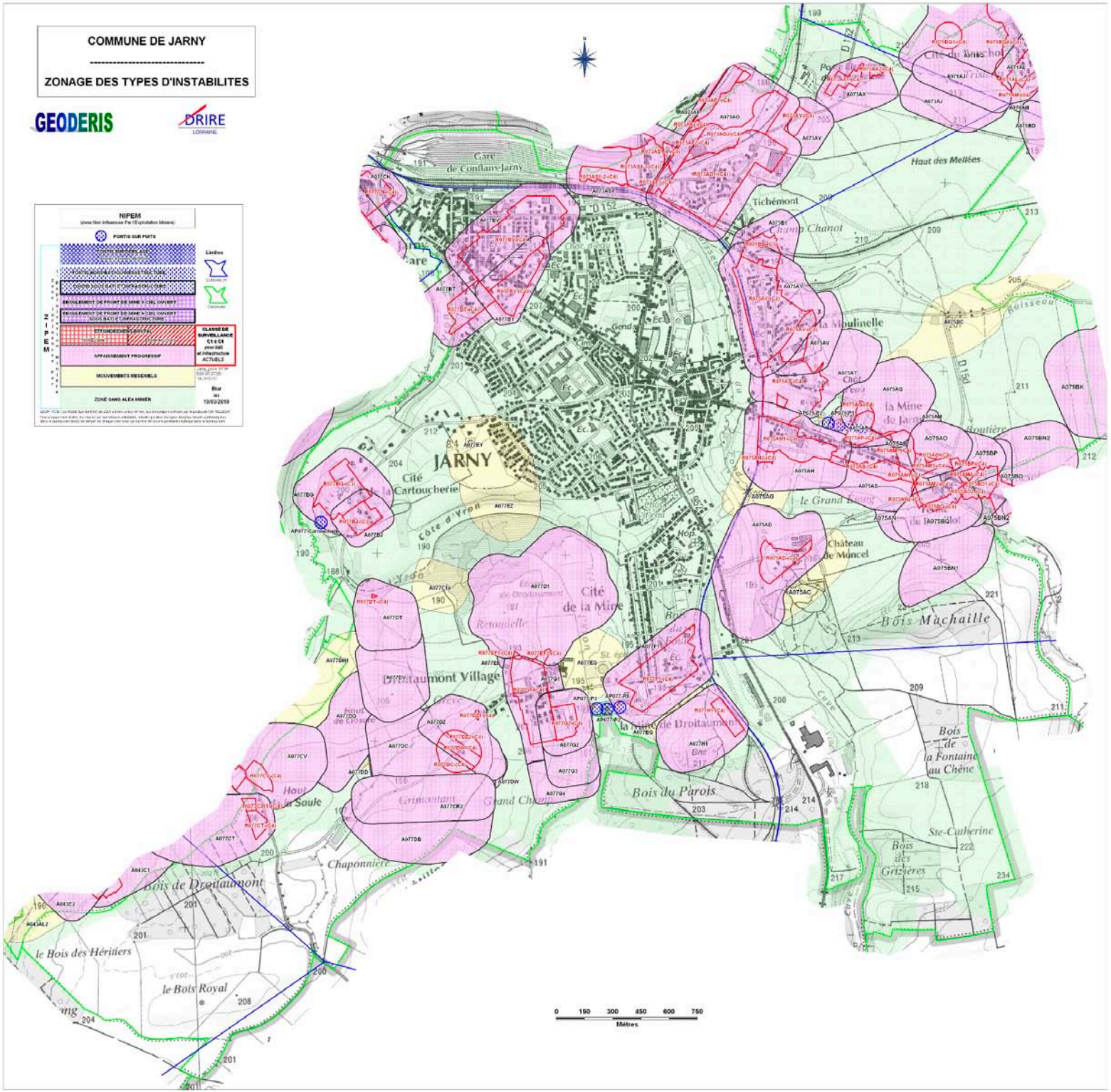
Score Summaries

The principle of hazard qualification consists then of combining criteria to characterize the collapses; for instance, geological criteria are used to further examine the 10 collapses classified as brutal by the discriminant analysis. ***The final hazard maps are the result of the whole process of expertise.***



70 collapses projected over the discriminant dimension

EXAMPLE OF A HAZARD ZONES MAP



- Progressive subsidence
- Sink hole
- Sink hole (low hazard)
- Sink hole (medium hazard)
- Sink hole (high hazard)
- Sudden collapse

FROM « WHAT IF? »
TO « WHAT FOR? » AND « SO WHAT? »

JMP AND STATISTICAL EXPERTISE

- **Statistics and Hypothesis Testing**

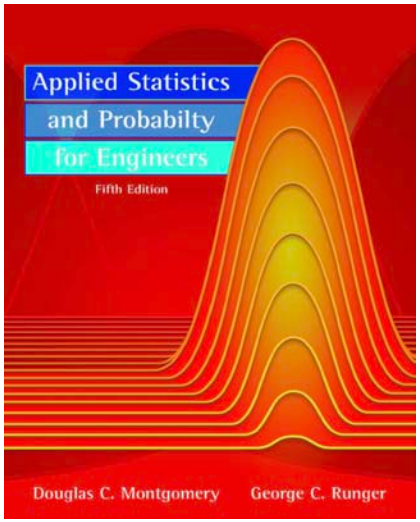
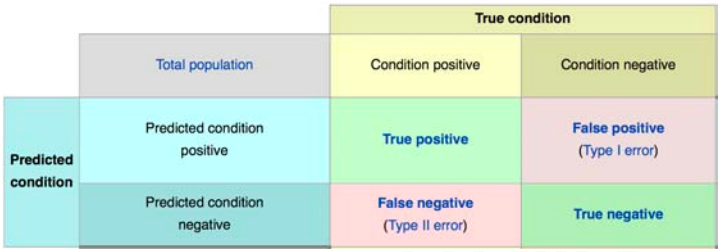
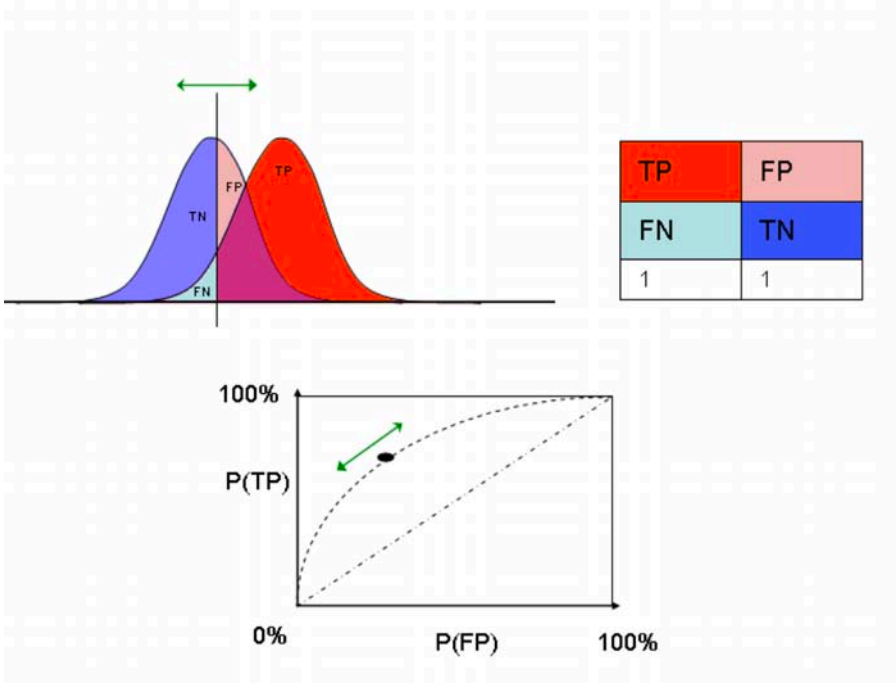


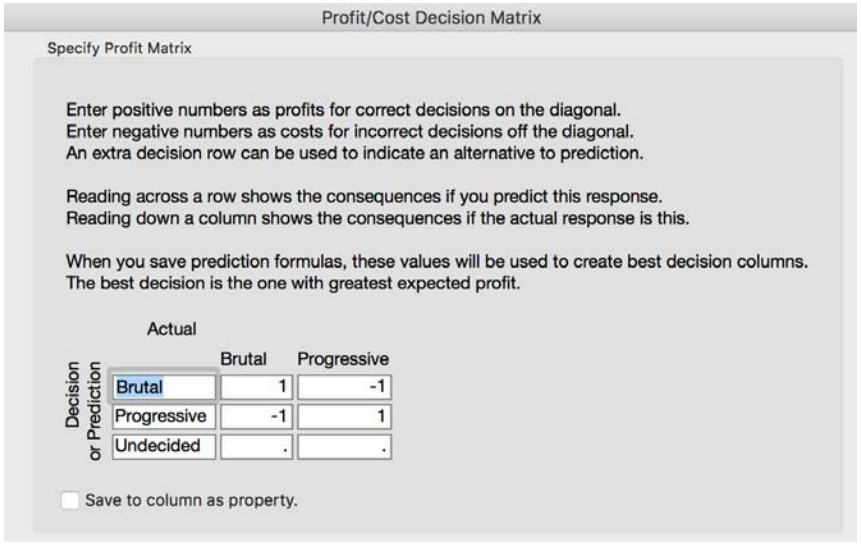
Table 9-1 Decisions in Hypothesis Testing

Decision	H_0 Is True	H_0 Is False
Fail to reject H_0	no error	type II error
Reject H_0	type I error	no error



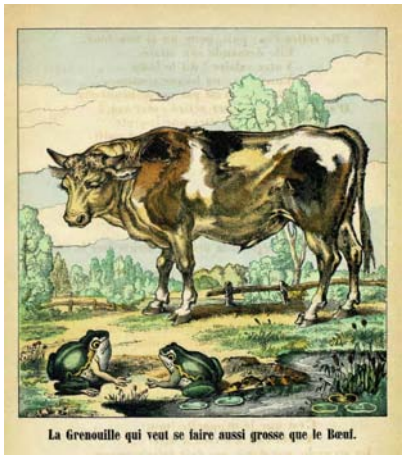


https://en.wikipedia.org/wiki/Receiver_operating_characteristic



JMP AND STATISTICAL EXPERTISE

- **As a SAS and JMP user (and teacher), I wanted to do with JMP the same things I can do with SAS (Yes We Can!)**

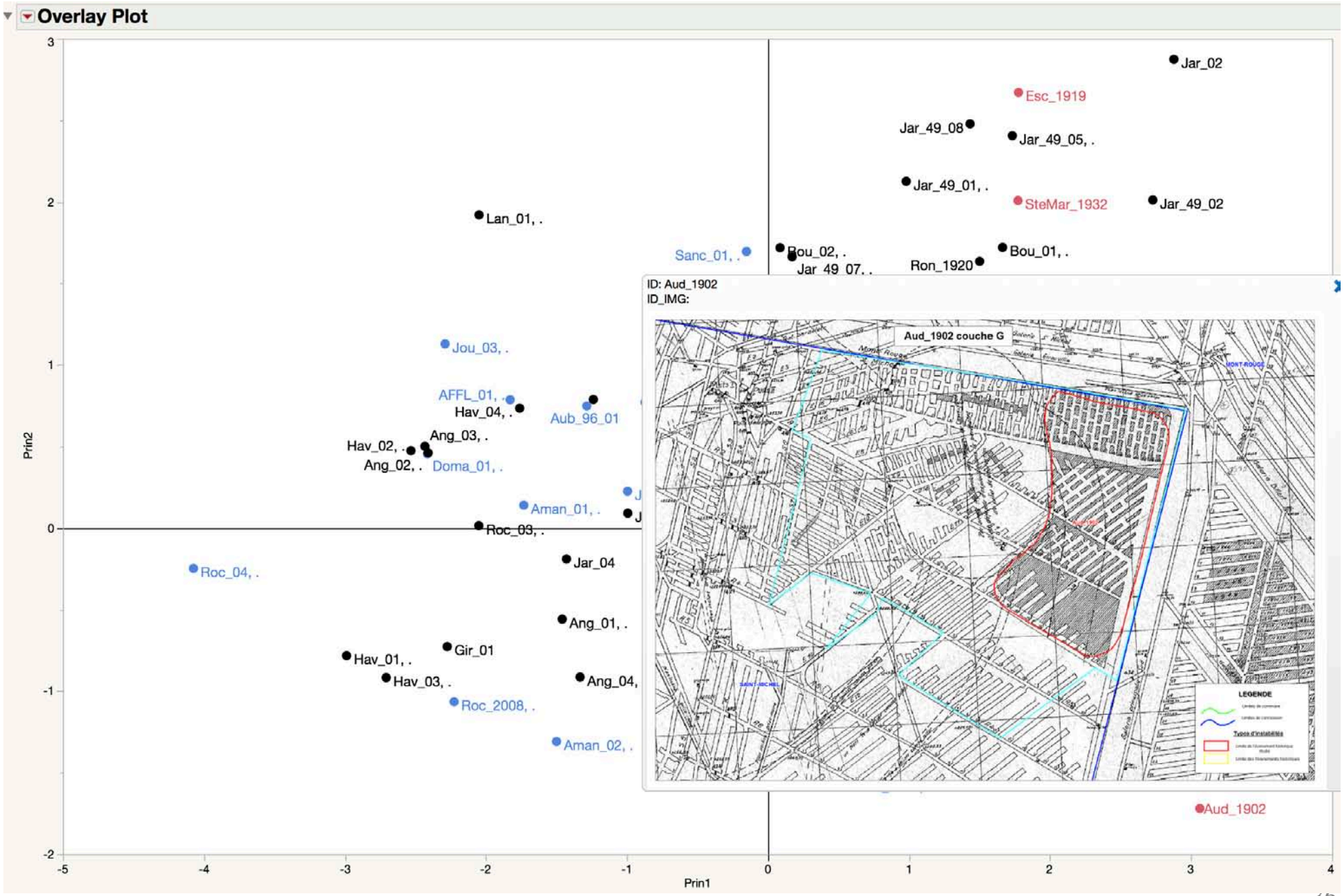


The Frog who Aspired to Become as Big as the Ox

- **BUT it's not the point!**

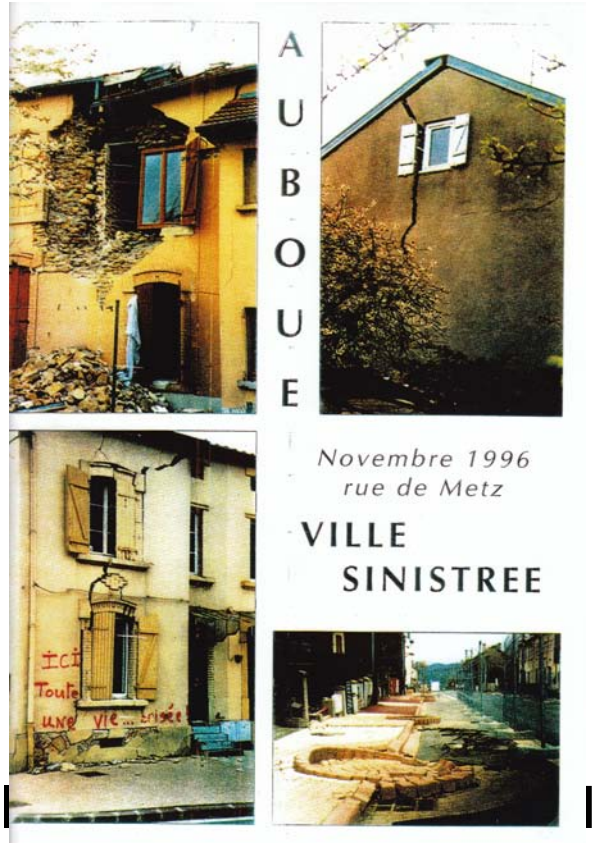
→ **With JMP, we can *play* the *What if?* questions *live* with the other experts**

JMP AND STATISTICAL EXPERTISE



JMP AND STATISTICAL EXPERTISE

MORE IMPORTANT: People are not mice nor fishes, they can ask questions to the (statistician) experts



→ JMP is the right tool led » statisticians to be more « proactive ».

JMP AND STATISTICAL EXPERTISE

But in fact, when it's time to assess 'how stable the situation is', we are talking in terms of risk and acceptance. It is now up to the stakeholders, not just to the experts or the engineers, to decide whether the situation is acceptable or not, and whether uncertainty on the result has to be reduced or not.

And a kind of *L'Aquila syndrome* is not so far...

AT FAULT?

In 2009, an earthquake devastated the Italian city of L'Aquila and killed more than 300 people. Scientists were on trial for manslaughter.

NEWS IN FOCUS

SPACE What makes landing on a comet so hard **p.172**

MEDICAL ETHICS Rules on clinical trials stir debate **p.174**

NEUROSCIENCE Evidence mounts for gut–brain link **p.178**

DEPRESSION The condition that causes a staggering burden of disability **p.179**

FILIPPO MONTEFORTE/AFP/GETTY

More than 300 people perished in the earthquake that struck the medieval centre of L'Aquila.

RISK ASSESSMENT

Scientists cleared of quake deaths

Italian appeals court says six seismologists were not guilty of manslaughter following the 2009 L'Aquila disaster.

BY ALISON ABBOTT & NICOLA NOSENGO

Six seismologists accused of misleading the public about the risk of an earthquake in Italy were cleared of manslaughter on 10 November. An appeals court overturned their six-year prison sentences and reduced to two years the sentence for a government official who had been convicted with them.

The magnitude-6.3 earthquake struck the historic town of L'Aquila in the early hours of 6 April 2009, killing more than 300 people.

The finding by a three-judge appeals court prompted many L'Aquila citizens to react with rage, shouting "shame" and saying that the Italian state had just acquitted itself, local media reported. But it comes as a relief to scientists around the world who had been following the unprecedented case with alarm.

"We don't want to have to be worried about the possibility of being prosecuted if we give advice on earthquakes," says seismologist Ian Main of the University of Edinburgh, UK. "That would discourage giving honest opinion."

The defendants themselves have mixed feelings. Giulio Selvaggi, former director of the National Earthquake Centre in Rome, says that although he is happy to be acquitted, "there is nothing to celebrate — because the pain of the people of L'Aquila remains".

In the months before the major earthquake struck, the region around L'Aquila had been subject to frequent, mostly low-magnitude tremors known as seismic swarms. Residents were alarmed by a local amateur earthquake predictor's claims that he had evidence of an impending quake, although geologists dismissed his methods as unsound.

A commission of experts met on 31 March 2009 to advise the government. According to the prosecution, a press conference after that meeting — attended by the acting president of the commission, volcanologist Franco Barberi of the University of Rome 'Roma Tre', and by Bernardo De Bernardinis, then deputy director of the Italian Civil Protection Department — conveyed a reassuring message that a major earthquake was not on the cards. Moreover, in a television interview recorded shortly before the meeting but aired after it, De Bernardinis said that "the scientific community tells me there is no danger because there is an ongoing discharge of energy" during the seismic swarms.

As a consequence, according to the prosecution, when the earthquake struck on 6 April, 29 people chose to stay indoors and died as their homes collapsed. All members of the expert commission were found guilty of manslaughter in October 2012, after a 13-month trial that transfixed the international scientific community.

In addition to De Bernardinis, Selvaggi and Barberi, the other defendants were Enzo Boschi, former president of the National Institute of Geophysics and Volcanology in Rome; Claudio Eva, an Earth physicist at the University of Genoa; Mauro Dolce, head of the seismic-risk office of the Civil Protection Department in Rome; and Gian Michele Calvi, director of the European Centre for Training and Research in Earthquake Engineering in Pavia.

Over the course of six hearings before the appellate court in L'Aquila, the defence argued that there was no proof of a causal link between the meeting and the behaviour of the people of L'Aquila citizens. The lawyers also argued that the scientists could not be held accountable for De Bernardinis's reassuring statements, and that their scientific opinions were ultimately correct.

De Bernardinis was acquitted of the manslaughter charges in 16 cases, but not for the other 13. The judges can take up to three months to publish the reasoning behind their verdict. Lawyers for the families of the deceased have announced that they will challenge the ruling in the Supreme Court of Cassation in Rome, which could call for a retrial. ■

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[→ The whole title of his conference this morning: The Design of JMP : *A few of my favorite things*]

Thank you for coming

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