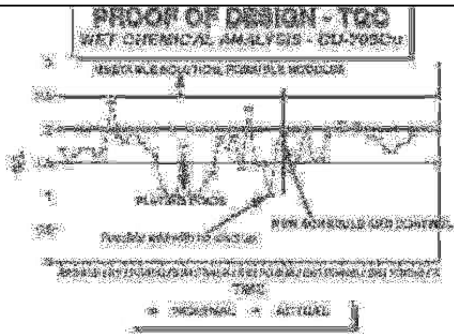
11.3.2 Printed Circuit Board Failure Analysis

As with all other F/A processes, PCB's occasionally need a little help from them. The following, just as the component process in Section previous, has been condensed from so many involvements over the past 35 years, **I cannot remember - nor should I because they all could have been prevented with DFM/CE**. However, the information presented, coupled with good DFM/CE and PCB process management provides an insight to the beast.

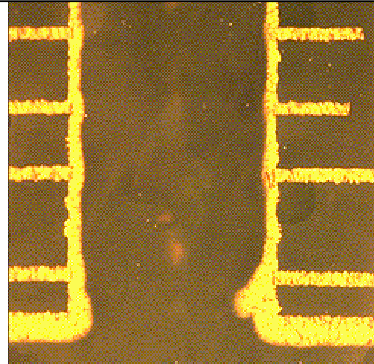
NOTE: FAILURE MODE AND EFFECT ANALYSIS (FMEA) IS THE TERM USED NOW TO BEST DESCRIBE AND DERIVE CAUSE AND EFFECT RELATIONSHIPS. IN THE WET CHEMICAL ANALYSIS PROCEDURES IN 11.3.1 (BEGINNING ON PAGE 210), IT IS MADE CLEAR HOW PCB CHEMISTRIES MUST BE ANALYZED, PRE-PROCESS AUDITED, CONTINUALLY MONITORED, AND EFFECTIVELY MANAGED TO ENSURE FAILURES ARE NOT FOUND. HOWEVER, IF A PROCESS GOES OUT OF CONTROL, SOME OF THE FOLLOWING INFORMATION IS USEFUL TO FIND ROOT CAUSE, CORRECT IT, AND PREVENT IT FROM RECURRING SO NO DEFECT IS FOUND AGAIN. THE FOLLOWING IMAGES PROVIDE CAUSE AND EFFECT RELATIONSHIPS WITH CAUSE ON THE LEFT AND EFFECT ON THE RIGHT. HOPEFULLY, THEY PROVIDE MOSTLY GRAPHIC/VISUAL INFORMATION WITH NEED OF FEW WORDS.

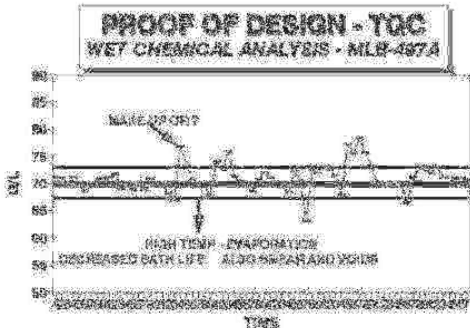
MLB HOLE AND LAMINATE INTEGRITY, PROPERTIES & DEFECTS SOME GOOD, BAD AND UGLY	PCB/DEVICE SOLDER TERMINATION AREA SURFACE FINISHES & DEFECTS MORE OF THE SAME
LABORATORY SOME MORE AND LAB STUFF	LABORATORY JUST A LITTLE MORE AND LAB STUFF

NICE KNOWING WHERE ONE IS AS CAUSE

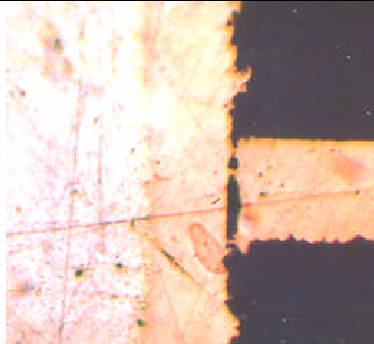


EFFECT TRACEABLE TO CAUSE

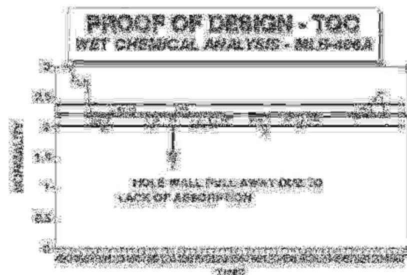




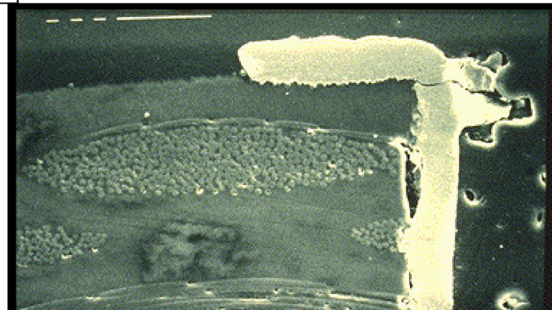
CAUSE



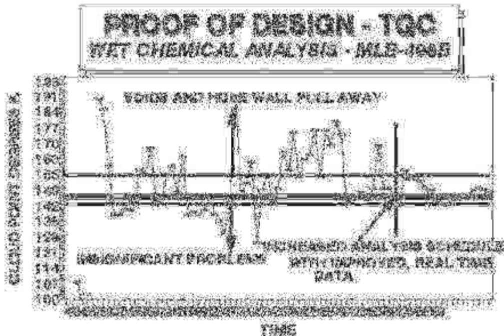
EFFECT AS RESIN SMEAR



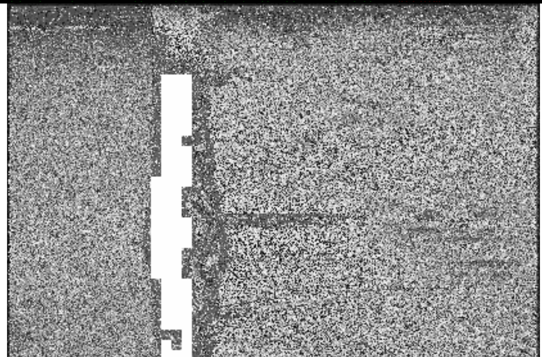
CAUSE



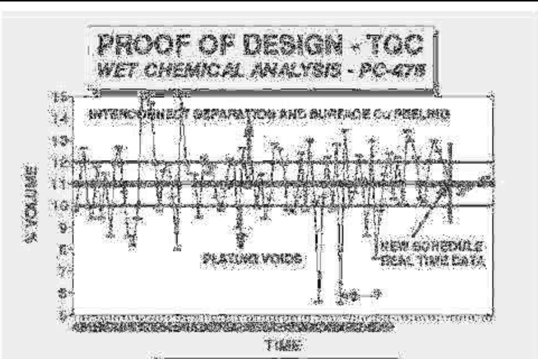
EFFECT AS HOLE WALL PULL AWAY AND....



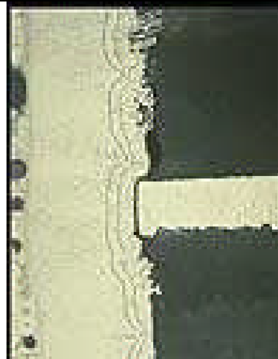
CAUSE



EFFECT AS HOLE WALL PULL AWAY AND...

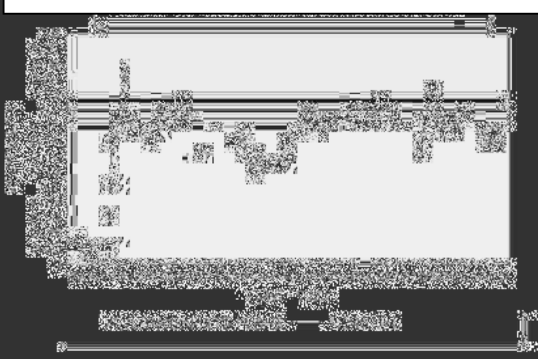


CAUSE

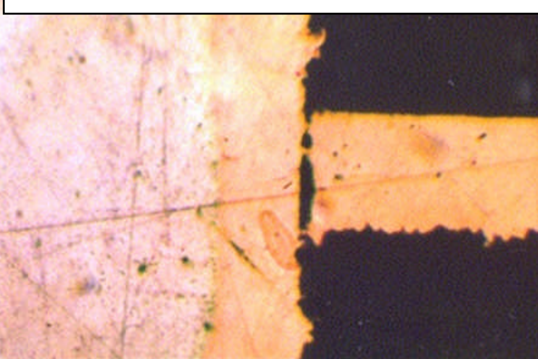


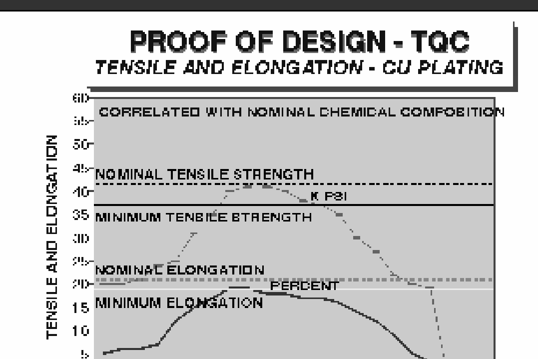
EFFECT AS INNER LAYER SEPARATION (ILS)

CAUSE AS POOR CHEM MAINTENANCE

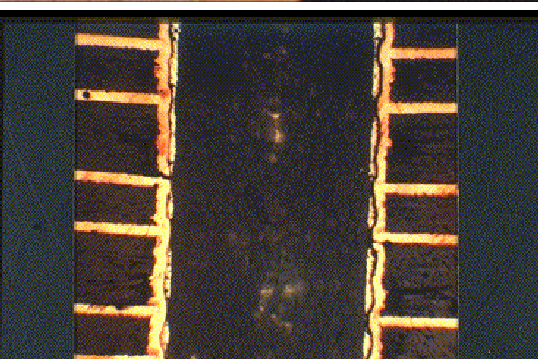


EFFECT AS REALLY BAD RESIN SMEAR

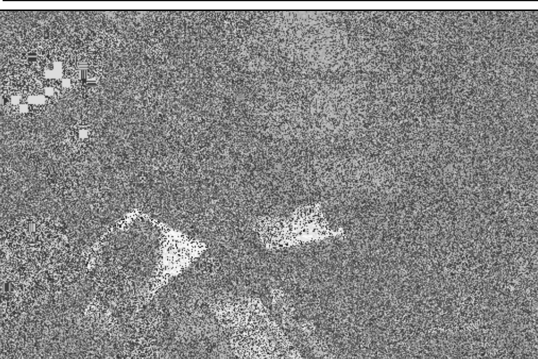




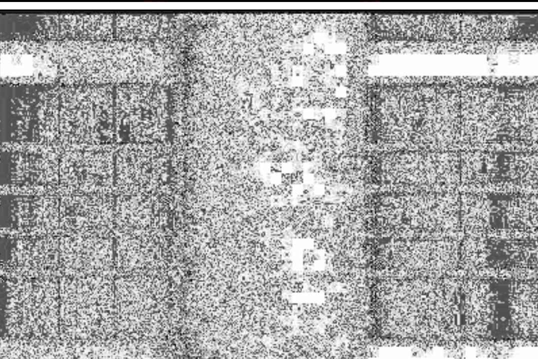
CAUSE AS CU PLATE BATH TEMPERATURE



ONE NEGATIVE EFFECT AS HOLE CRACK



CAUSE AS GOOD PRE-PROCESS AUDITING



EFFECT AS NEAR PERFECT PLATED HOLE

NOTE: THERE IS SO MUCH MORE TO TALK ABOUT HERE. HOWEVER, THE GOOD THING IS PCB FAILURE ANALYSIS IS STRAIGHT FORWARD. THAT IS, IT IS FAIRLY EASY TO DETERMINE CAUSE AND EFFECT RELATIONSHIPS FROM CHEMISTRY AND MATERIAL PROCESS MANAGEMENT THROUGH ALL PROCESSES FOLLOWING. THIS MEANS CORELATION BETWEEN FINDINGS, AS DEFECT, AND CAUSE ALWAYS CAN BE MADE.

IT'S CAF (CONDUCTIVE ANODIC FILAMENT) TIME

This brief but important series of images is provided courtesy of the folks at the Georgia Institute of Technology, at the time they were there (first image below). This brief provides a detailed insight into conductive anodic filament issues though saying little about its prevention even though the answers are there but must be uncovered. For that, see the MoonMan's information in Table II and his presentation on multilayer PCB requirements. In this information are found details that prevent most CAF occurrences from a multilayer construction perspective - especially using more resin rich materials. As far as certain flux chemistries go, that is another matter of vital interest.

Conductive Anodic Filament (CAF) Formation:
A Potential Reliability Problem for Fine-Line Circuits

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http://reliability.marc.gatech.edu/

What exactly is CAF?

- Conductive Anodic Filaments are copper corrosion by-products that emanate from the anode of a circuit and "grow" subsurface toward the cathode, frequently along separated fiber-epoxy interfaces.

+ Anode - Cathode CAF
Top of P9
e-glass fibers ~10 µm diameter

CAF Background

- Two step process.
- $t_{failure} = t_1 + t_2$
  - » t_1 is related to the degradation of fiber/epoxy interface.
  - » t_2 is related to the rate of the electrochemical corrosion reaction.
  - » $t_1 >> t_2$

t_1, Degradation of Interface

- Mechanical stress.
- Poor quality coupling agent.
  - » Promotes adhesion between fiber and epoxy during PWB/MLB "lay-up" operations.
- Thermal stress.
  - » Multiple soldering excursions cause thermal fatigue.
- Moisture attack.

t_2, Electrochemical Reaction

Anode:

$Cu \rightarrow Cu^{n+} + ne^-$

$H_2O \rightarrow \frac{1}{2} O_2\uparrow + 2H^+ + 2e^-$

Cathode:

$2H_2O + 2e^- \rightarrow H_2\uparrow + 2OH^-$

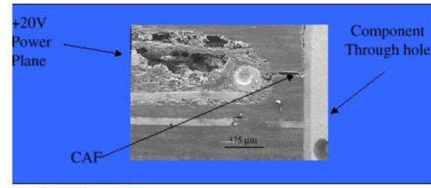
$Cu^{n+} + ne^- \rightarrow Cu$

Factors Which Enhance CAF Formation

- High humidity (~80% RH anytime during life of product).
- High voltage gradient between anode and cathode (~3-8 V/mil.).
- Certain soldering flux ingredients.
- Hole drilling.
- Multiple thermal cycles during processing.

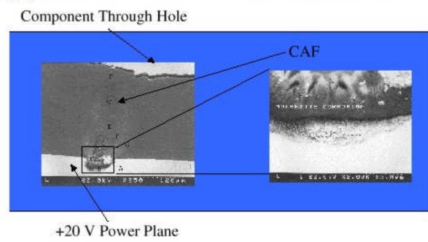
Catastrophic Field Failure of Military Hardware, Flux Enhanced Degradation

- CAF, if allowed to bridge the gap between anode and cathode of the circuit, will create a “short” in the assembly.



Catastrophic Field Failure of Military Hardware

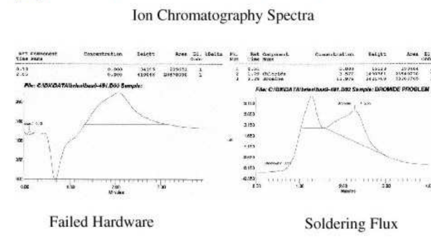
Component Through Hole



+20 V Power Plane

Catastrophic Field Failure of Military Hardware

Ion Chromatography Spectra



Failed Hardware

Soldering Flux

Laboratory Experiments

	[illegible]	[illegible]	[illegible]	[illegible]
pH	2.75	3.2	3.2	3.2
Ingredients and Percentages as Listed in MSDS or in Product Literature	Isopropyl Alcohol (75 - 90%)	Isopropyl Alcohol (75 - 85%)	Isopropyl Alcohol (75 - 85%)	Isopropyl Alcohol (75 - 85%)
	HBr (<5%)		Amine HBr	Amine HCl
	Polyglycol	Triisopropanolamine	Triisopropanolamine	Triisopropanolamine
		Polyol	Polyol	Polyol
Color	clear to pale yellow	clear to pale yellow	clear to pale yellow	clear to pale yellow
Flash Point	60°F	59°F	59°F	59°F
Specific Gravity	0.87	0.83	0.83	0.83
Use	foam, wave, or spray flux for SMT or Through Hole	foam, wave, or spray flux for SMT or Through Hole	foam, wave, or spray flux for SMT or Through Hole	foam, wave, or spray flux for SMT or Through Hole

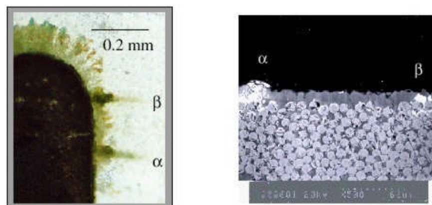
Laboratory Experiments

	[illegible]	[illegible]	[illegible]	[illegible]
pH	6.8	2	2	<3.0
Ingredients and Percentage as Listed in MSDS or in Product Literature	2-Propanol (64%)	Ethoxylated Polyoxypropylene (35%)	Isopropyl Alcohol (70%)	
	Chloride (2%)	HBr (15%)		HBr (10%)
	Surfactants	Polyalkylene Glycol (35%)		Nonionic Surfactant (75%)
	Glycerol (11%)	Polyglycol (15%)		
	Organic Acids			
Color	pale amber to amber	clear to light yellow	clear to pale yellow	clear to dark amber
Flash Point	60°F	525°F	60°F	600°F
Specific Gravity	0.8	1.08	0.92	1.09
Use	wave flux	HASL / SMT	IR flux	vertical HASL

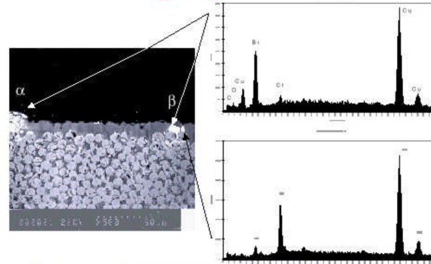
Flux used in field failure.

Laboratory Experiments

CAF formed with *same* flux (Flux 4) that caused military field failure.

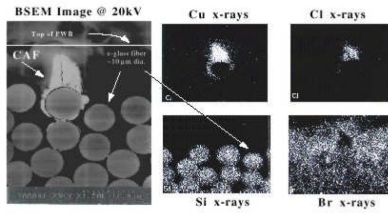


Laboratory Experiments



Laboratory Experiments

Wave Soldered FR-4 PWB
Treated with Flux 1



Laboratory Experiments

- Flux Chemistry Dependence
  - » CAF is frequently copper - chloride containing, but copper - bromide containing CAF has also been observed.
  - » All polyglycol containing fluxes (1,3,4 & 5) exhibited CAF.
  - » HBr and HCl in flux formulations were only deleterious when coupled with a polyglycol.

Conclusions

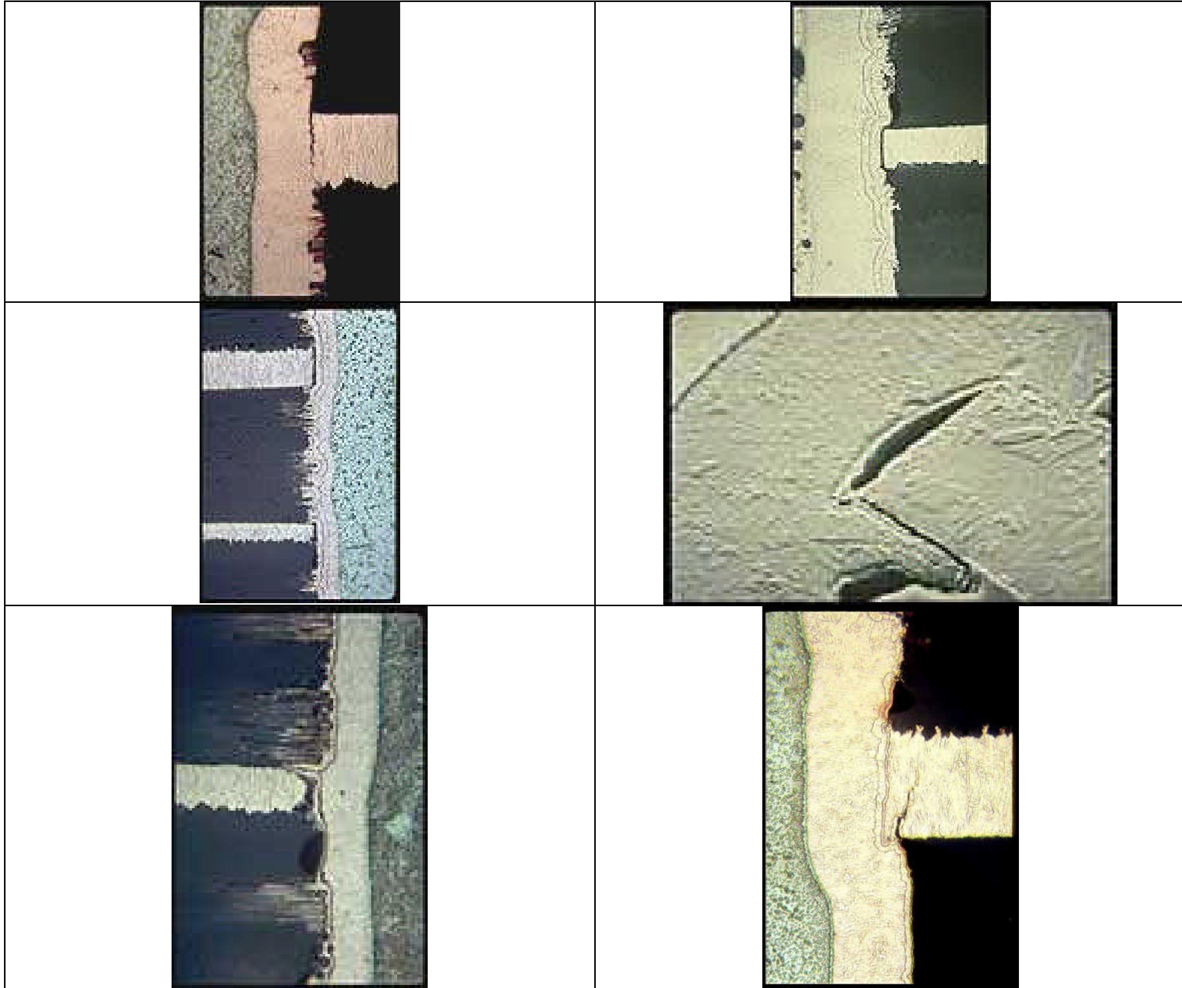
- High density circuits have voltage gradients that make CAF formation a possibility.
- Catastrophic field failures can be linked to the flux and HASL used in manufacture.
- Tests on 5 flux chemistries reveal CAF when certain polyglycols were present.
- Future work is focusing on identifying the "bad" polyglycols.

Acknowledgements

- Funded by U.S. Army Missile Command (MICOM)
  Contract # DAAH01-920D-R005-0013
  &
  Contract # DAAH01-920D-R005-0039.

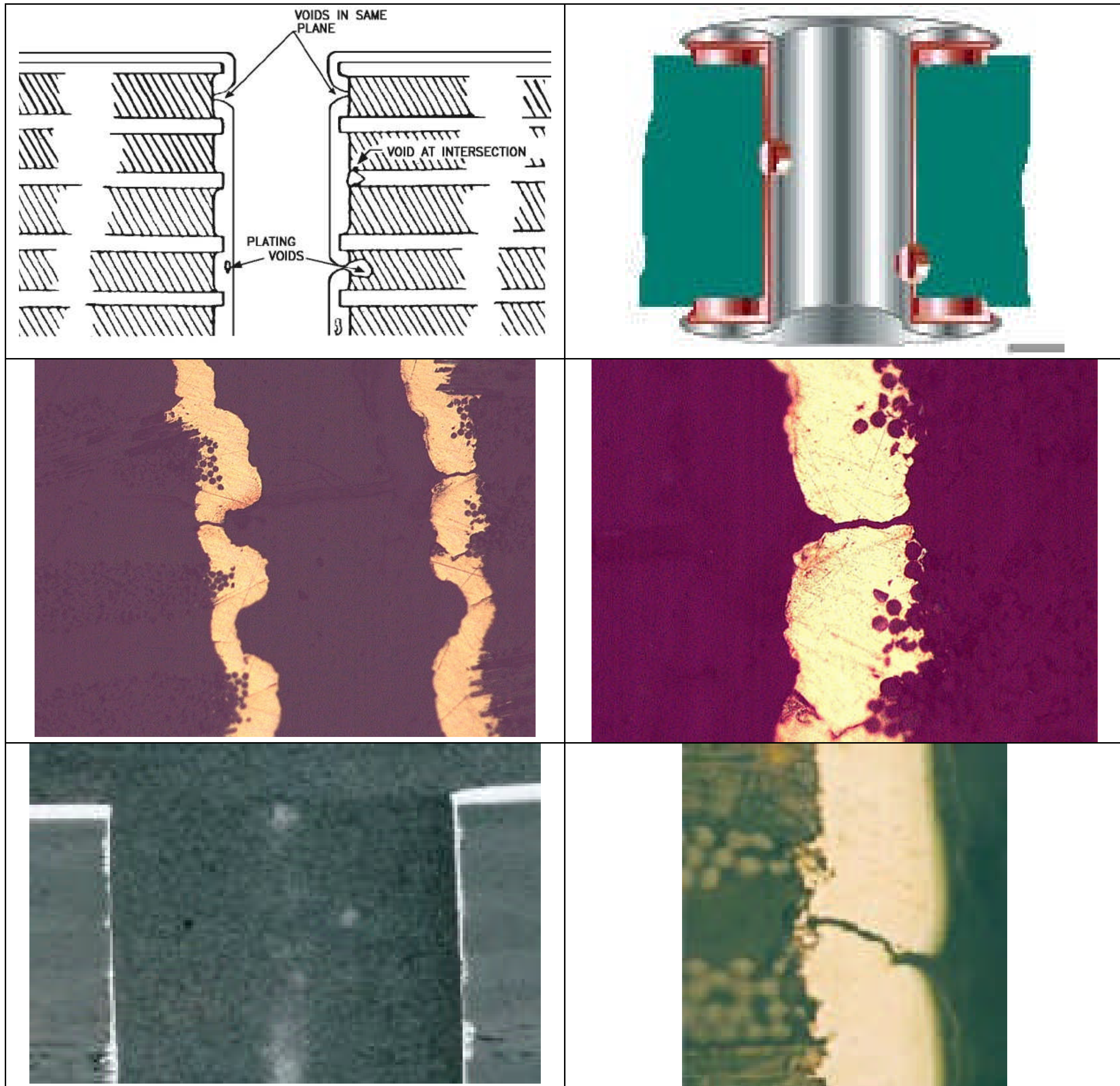
IT'S ILS (INNER LAYER SEPARATION) TIME

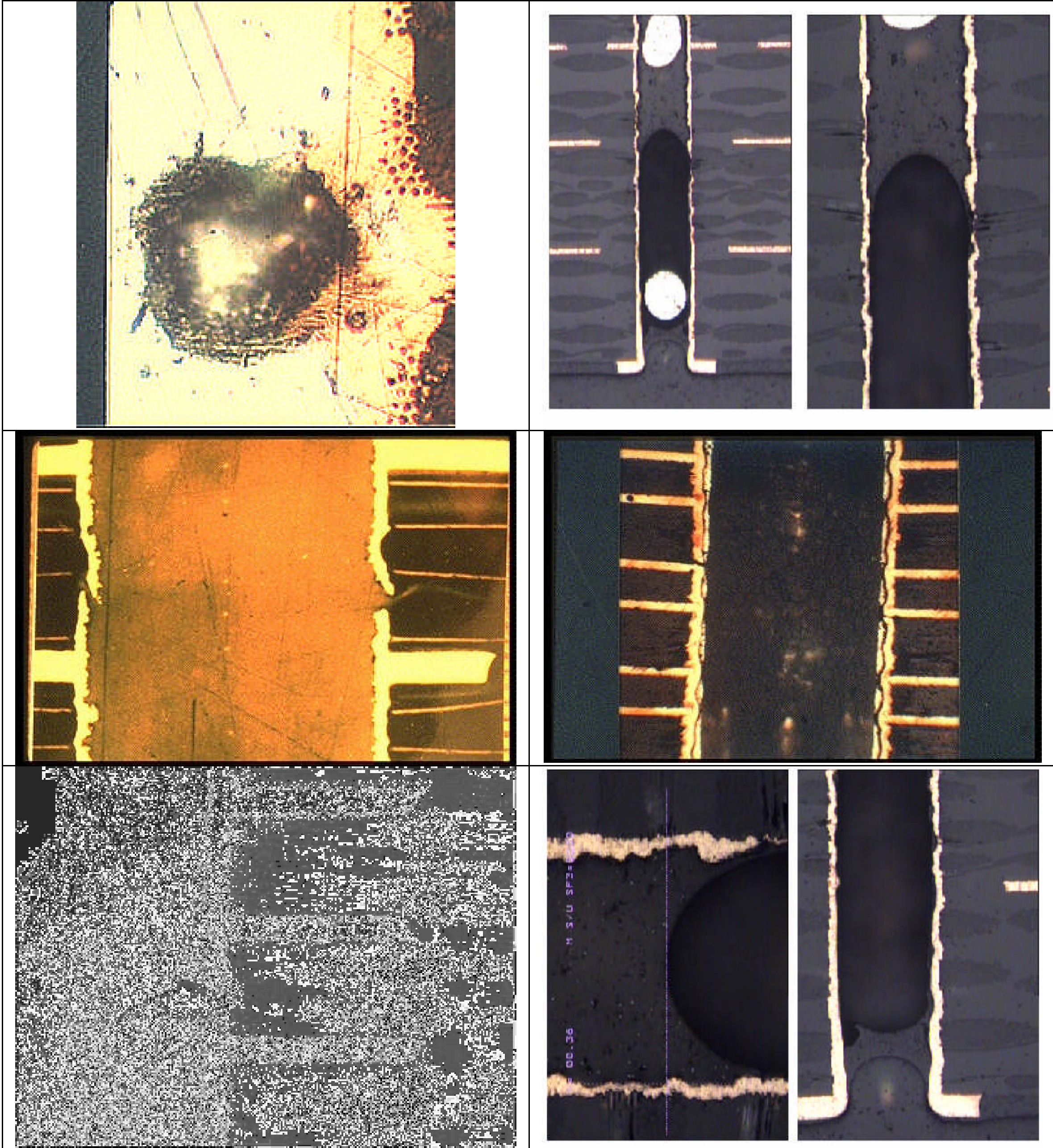
Inner layer separation images are in the following. ILS is easily prevented as indicated in the foregoing information concerning plating and other MLB required chemistries. There is no need to see any of this.



SOME PLATING VOIDS, IF YOU PLEASE

Again, managing plating chemistries prevent plating void occurrences as in the following. Read MoonMan's presentation on printed circuit basics as in the laboratory analytical, maintenance, and prevention section herein to ensure these little beauties do not come into your lives and wreak havoc. Remember what constitutes plating voids as in the first image, in MIL-P-55110, and the second in IPC - 600.





IMPORTANT NOTE: **CORELATION OF EFFECT (DEFECT) FINDINGS ARE EASILY MADE DIRECTLY TO INITIAL LABORATORY ANALYSIS, IN 11.3.1 STARTING ON PAGE 210, AND TO EFFECTIVE, OR NOT, PROCESS, INSTEAD OF RESULTS, MANAGEMENT.**