EVOLUTION OF RESERVOIR MANAGEMENT TECHNIQUES

From Independent Methods to an Integrated Methodology

Impact on Petroleum Engineering Curriculum, Graduate Teaching and Competitive Advantage of Oil Companies

SPE 39713, Kuala Lumpur, Malaysia, 23–24 March 1998.

Alain C. Gringarten
Imperial College, London

CONTENT

- RESERVOIR MANAGEMENT PROCESS
  - DEFINITION
  - OBJECTIVES
  - METHODOLOGY
  - IMPLEMENTATION
- IMPACT ON COMPETITIVE ADVANTAGE
- PETROLEUM ENGINEERING CURRICULUM

RESERVOIR MANAGEMENT

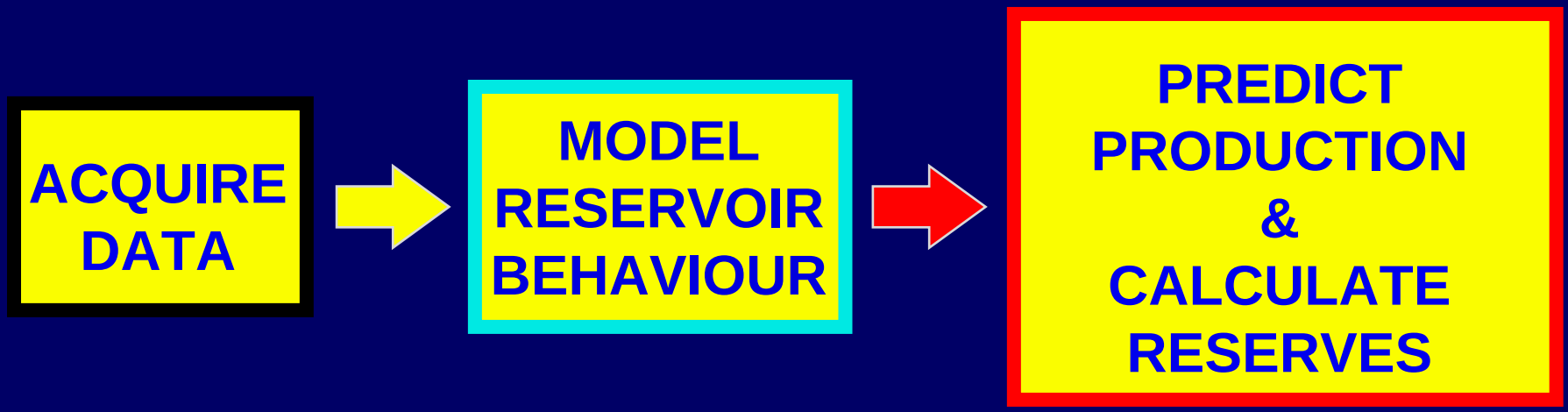
- APPLICATION OF AVAILABLE TECHNOLOGY AND KNOWLEDGE
- TO A RESERVOIR SYSTEM
- WITHIN A GIVEN MANAGEMENT ENVIRONMENT
- IN ORDER TO CONTROL OPERATIONS AND MAXIMISE ECONOMIC RECOVERY

OBJECTIVES
OF RESERVOIR MANAGEMENT

- DECREASE RISK
- INCREASE OIL AND GAS PRODUCTION
- INCREASE OIL AND GAS RESERVES
- MINIMISE CAPITAL EXPENDITURES
- MINIMISE OPERATING COSTS
- MAXIMISE RECOVERY

RESERVOIR MANAGEMENT TOOL:

MODELLING THE RESERVOIR BEHAVIOUR TO MAKE DECISIONS



THE MODELLING PROCESS

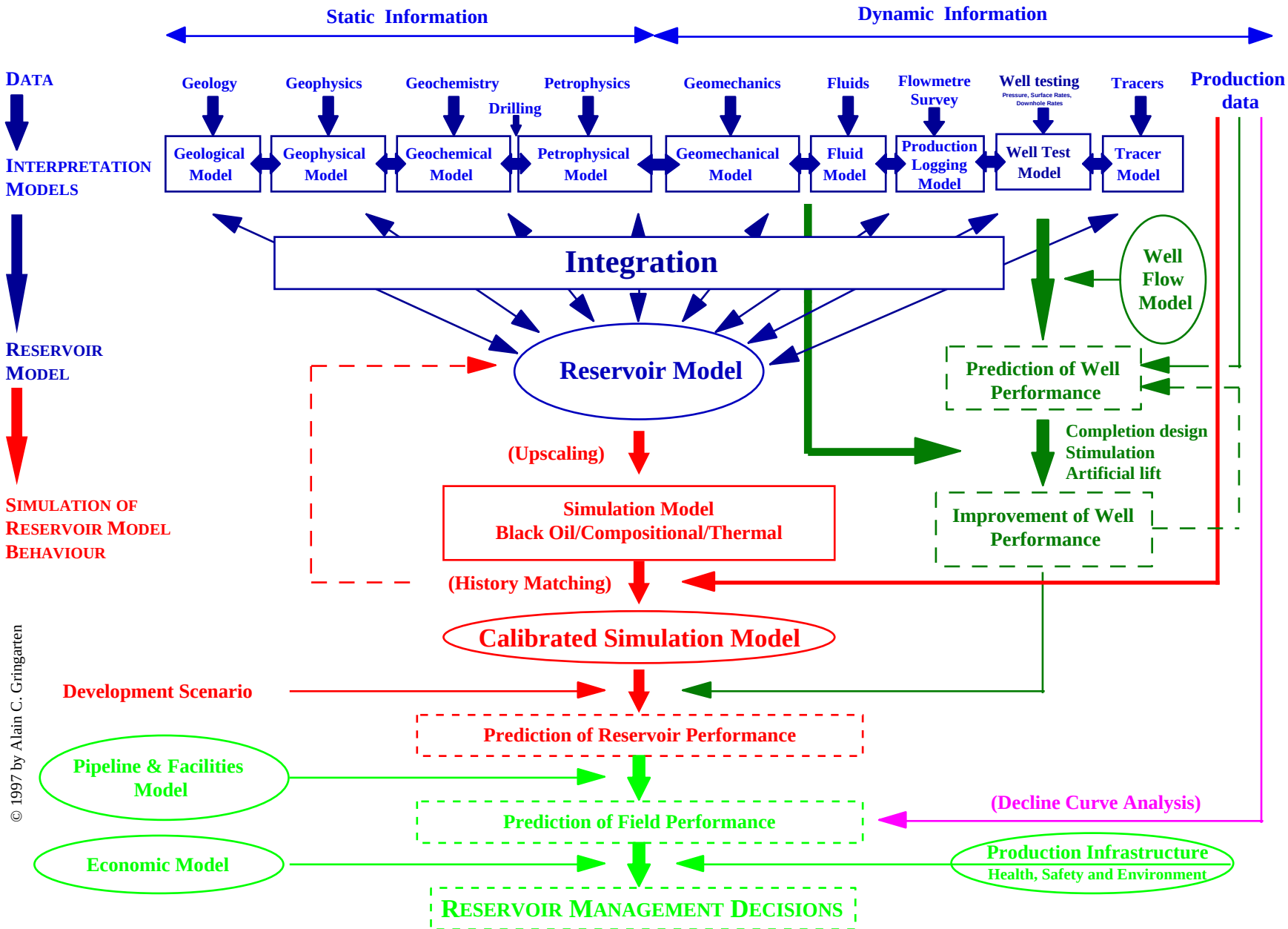
1. **IDENTIFICATION OF A RESERVOIR MODEL**
   RESERVOIR CHARACTERISATION (INVERSE PROBLEM)

2. **CALCULATION OF THE RESERVOIR MODEL BEHAVIOUR**
   UPSCALING AND SIMULATION

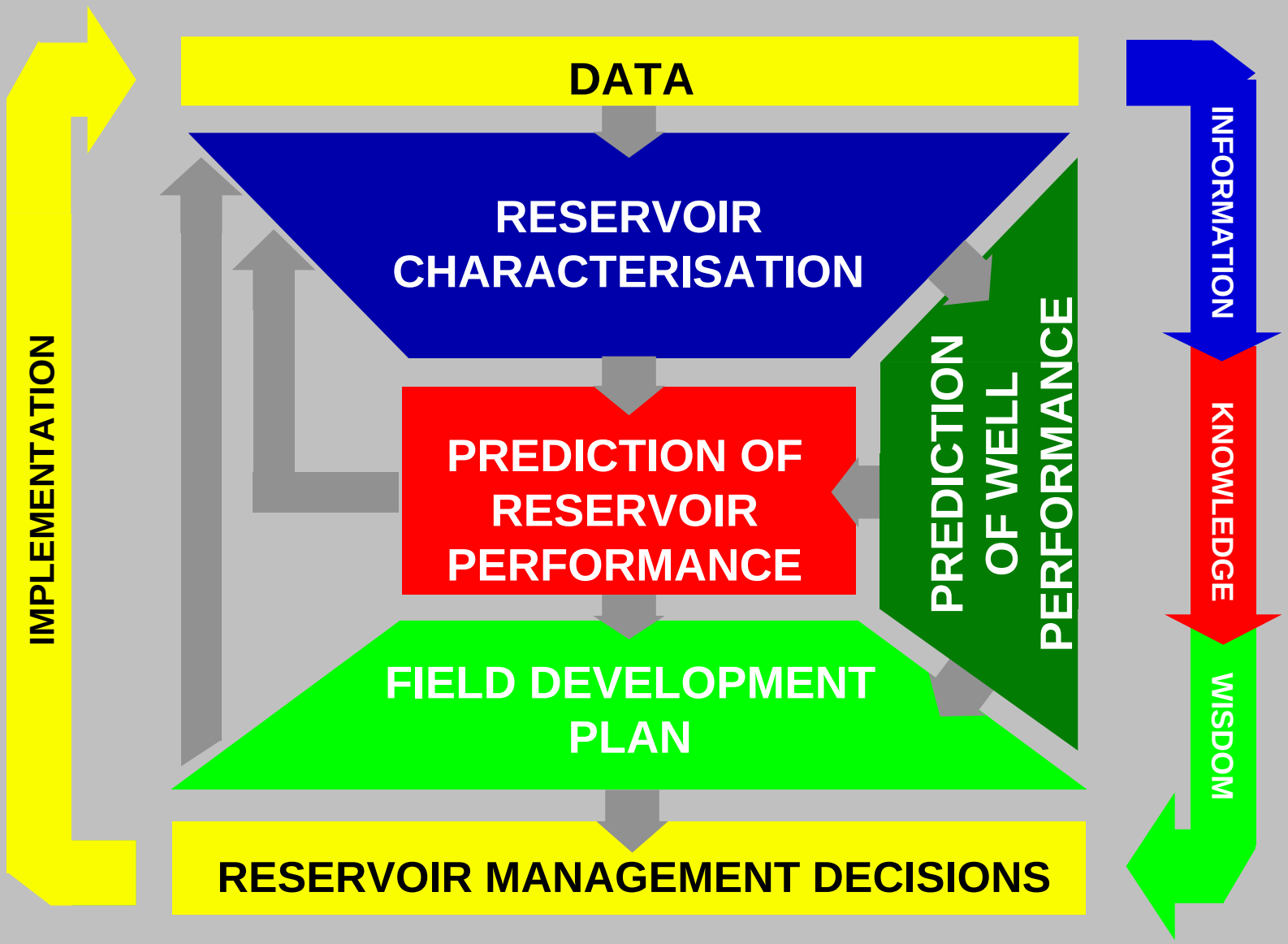
3. **MATCHING OF RESERVOIR SYSTEM PAST PERFORMANCE**
   HISTORY MATCHING (DIRECT PROBLEM)

4. **PREDICTION OF RESERVOIR SYSTEM FUTURE PERFORMANCE**
   (DIRECT PROBLEM)

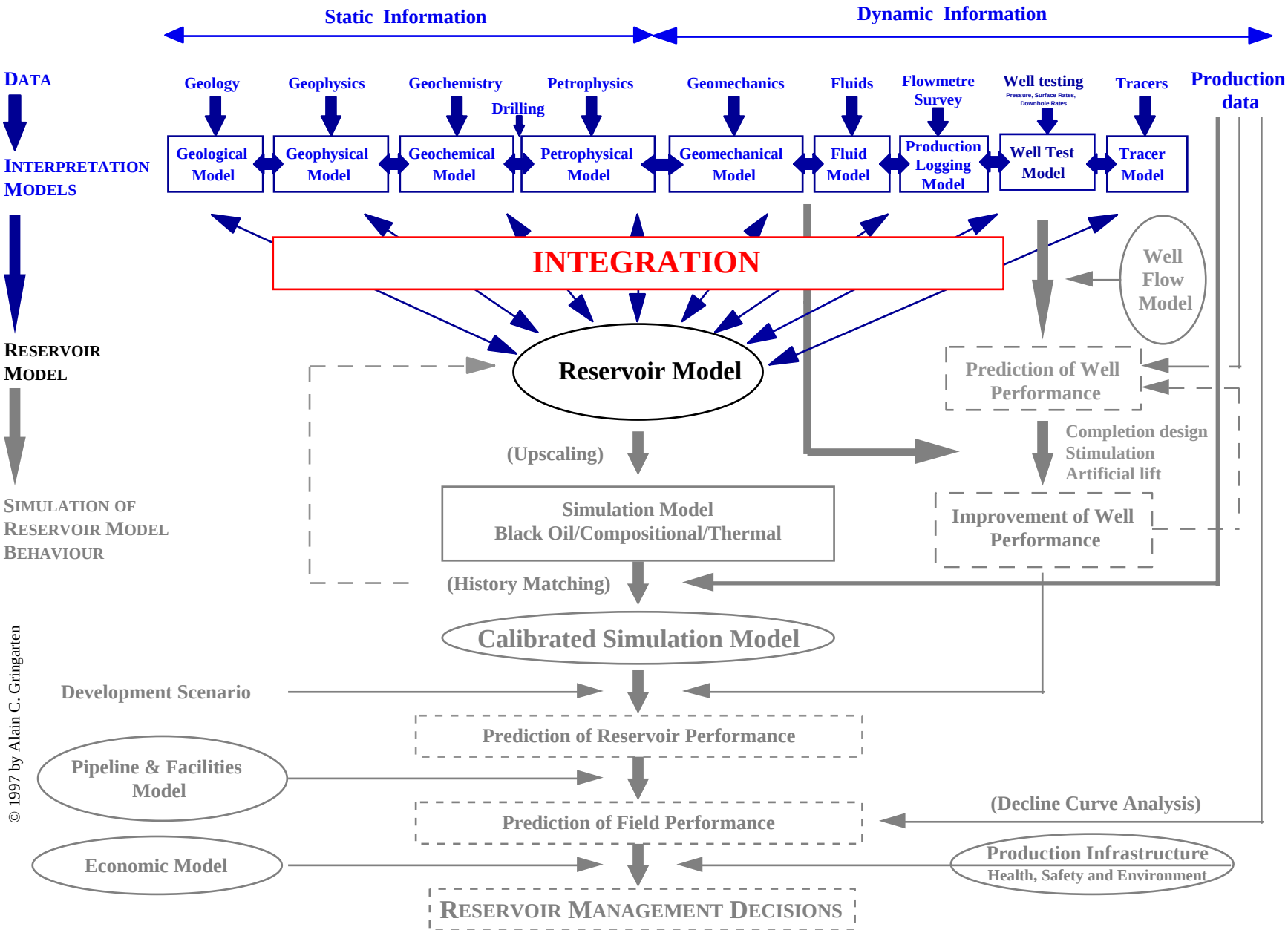
RESERVOIR MANAGEMENT PROCESS



THE RESERVOIR MANAGEMENT PROCESS



RESERVOIR CHARACTERISATION



RESERVOIR CHARACTERISATION

- **INTEPRETATION OF DATA**

>> STATIC INTERPRETATION MODELS (DESCRIPTION)

GEOPHYSICS, GEOLOGY

GEOCHEMISTRY

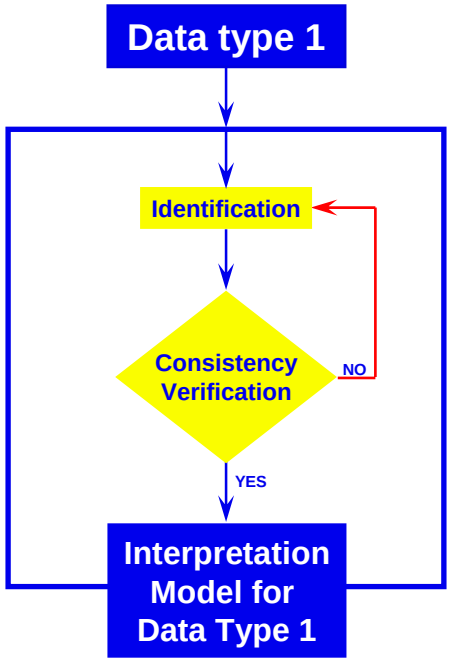
PETROPHYSICS

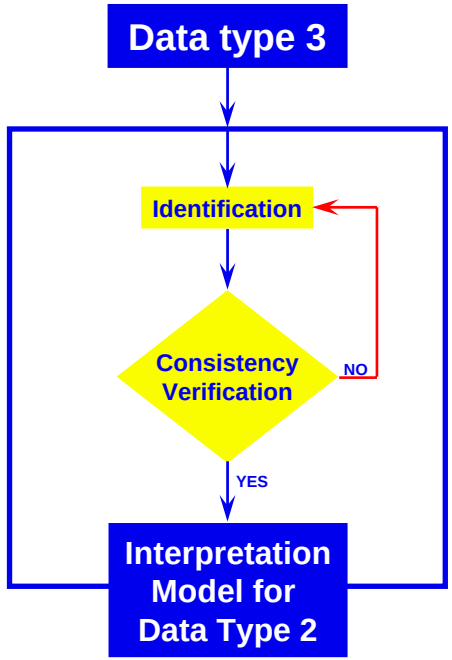
>> DYNAMIC INTERPRETATION MODELS (BEHAVIOUR)

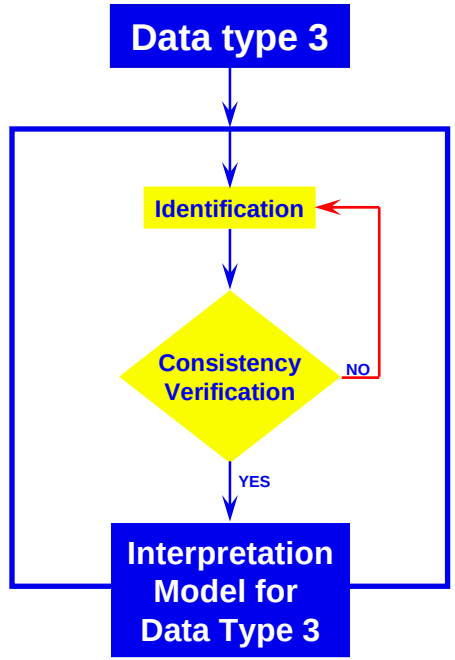
GEOMECHANICS

WELL TESTS, TRACERS

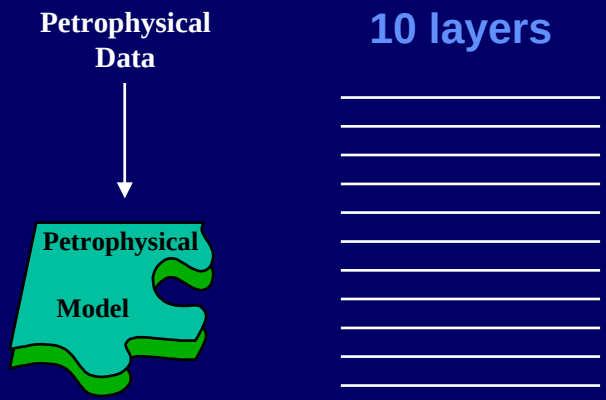
FLOWMETRE SURVEYS

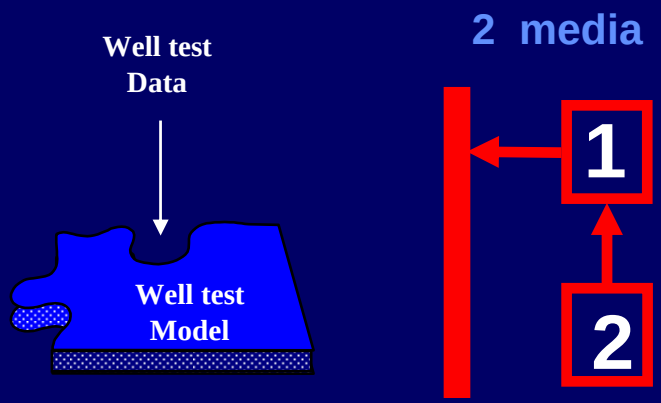

Data type 1
Identification
Consistency Verification
NO
YES
Interpretation Model for Data Type 1

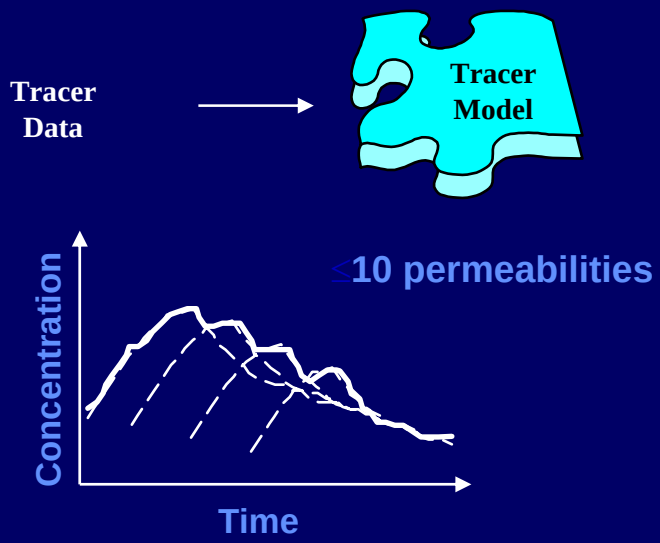

Data type 3
Identification
Consistency Verification
NO
YES
Interpretation Model for Data Type 2

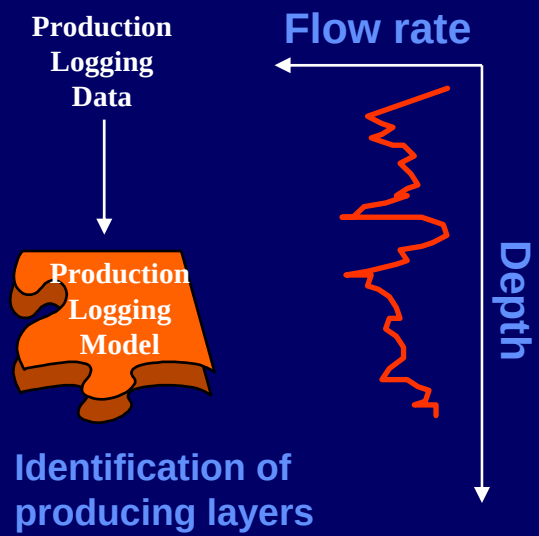

Data type 3
Identification
Consistency Verification
NO
YES
Interpretation Model for Data Type 3

INTERPRETATION MODELS

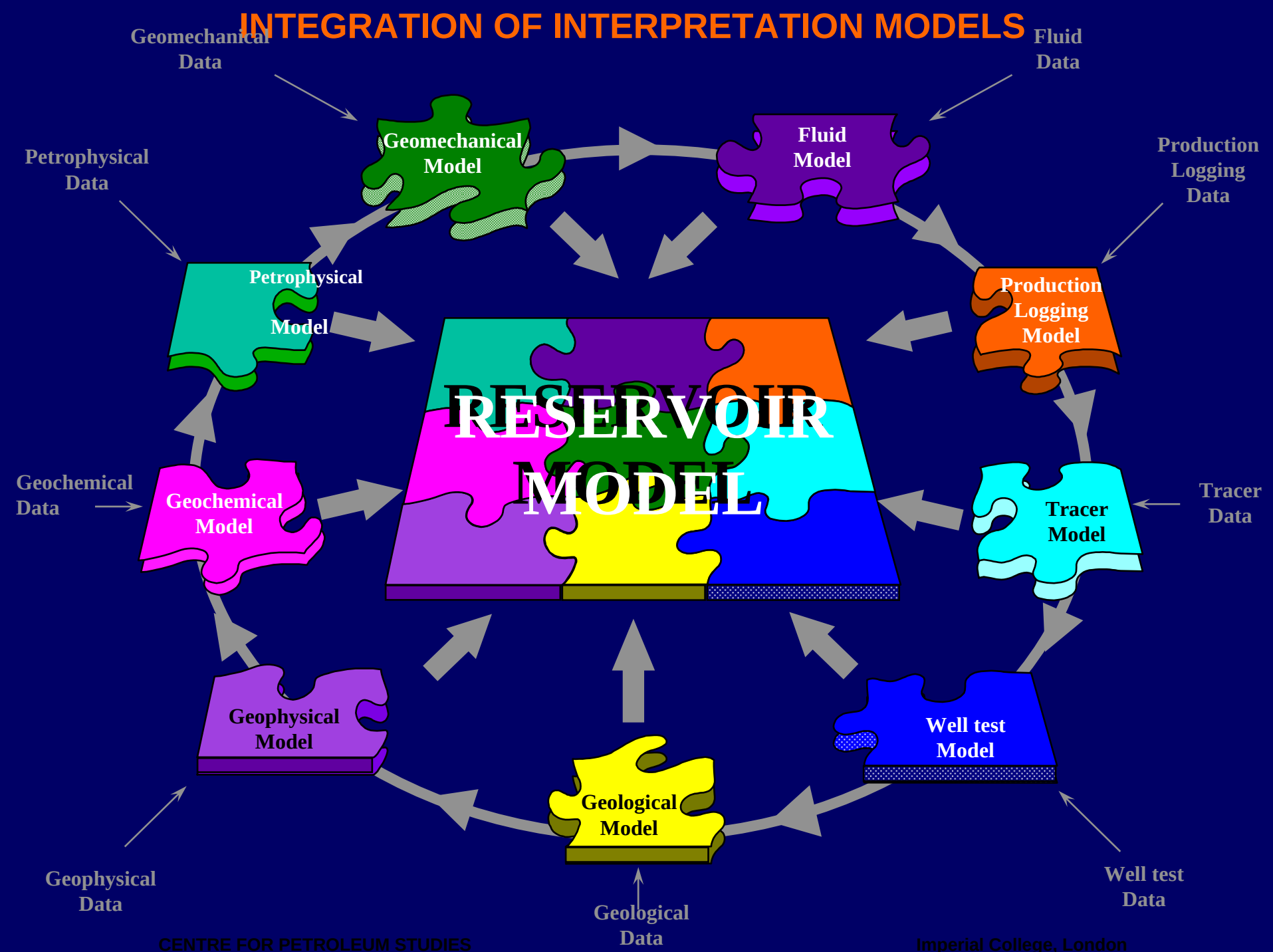








INTEGRATION OF INTERPRETATION MODELS



INTEGRATION OF INTERPRETATION MODELS

- **DETERMINISTIC TECHNIQUES**
- **STOCHASTIC TECHNIQUES**

>> INTERPOLATION BETWEEN SPARSE DATA (WELLS) AND EXTRAPOLATION

>> CORRELATION AND ORDERING OF INFORMATION

>> INTEGRATION OF INFORMATION (CONDITIONING)

FROM DIFFERENT DATA SOURCES

WITH DIFFERENT LEVELS OF RELIABILITY

>> GENERATION OF MULTIPLE, EQUIPROBABLE REALISATIONS OF THE RESERVOIR (PARAMETER DISTRIBUTIONS)

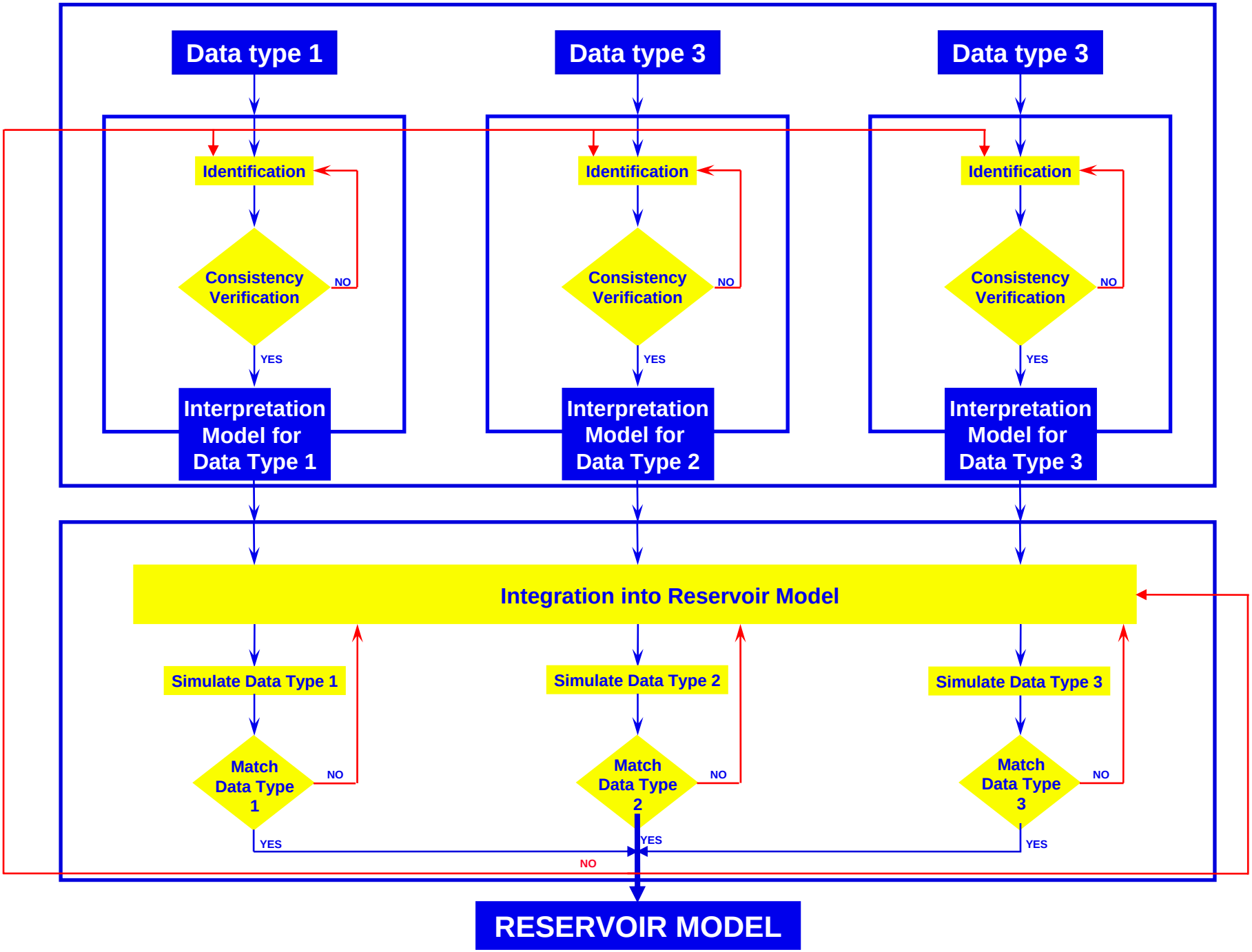
>> QUANTIFICATION OF UNCERTAINTIES

RESERVOIR MODEL VERIFICATION

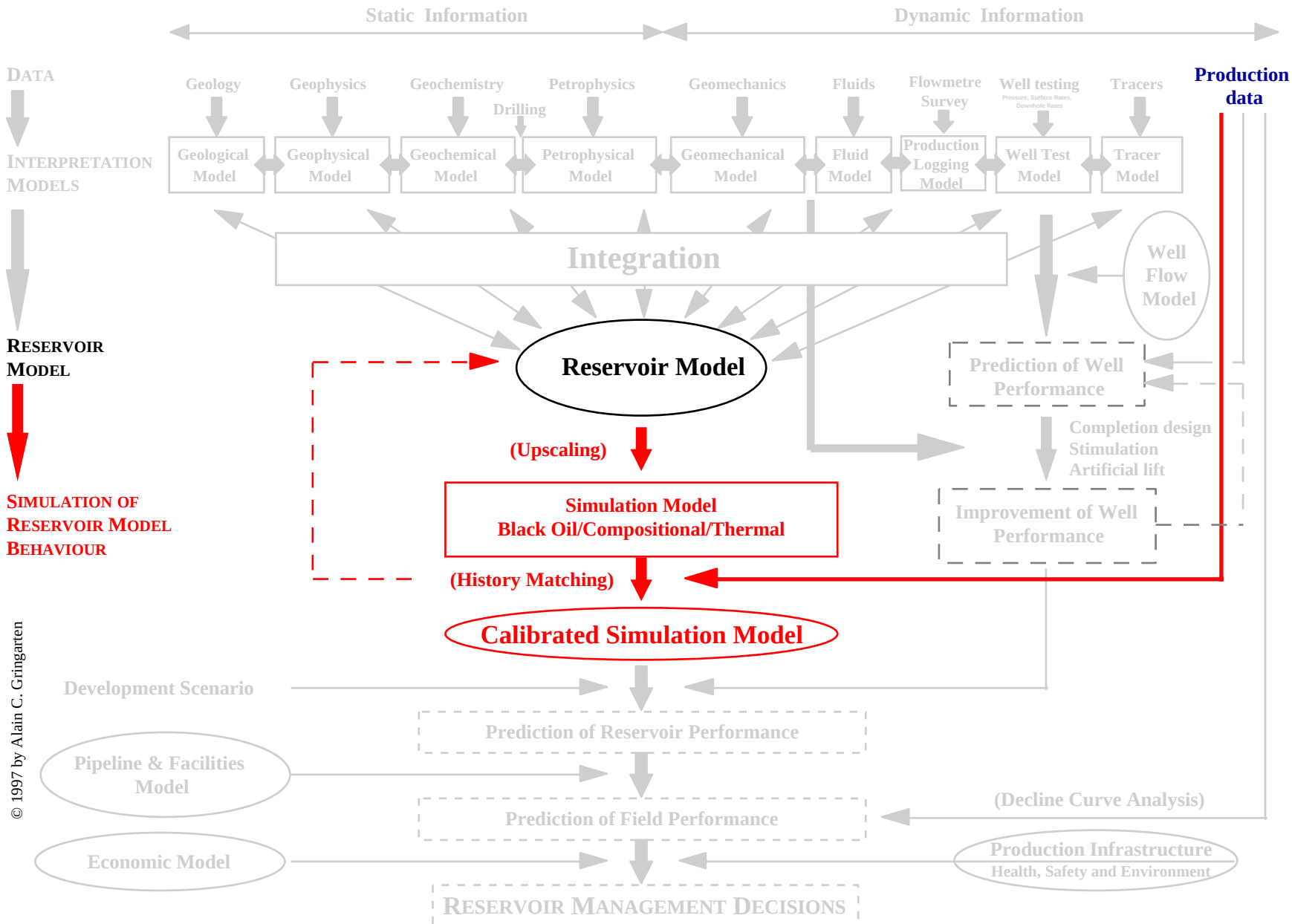
- **Once the reservoir model is constructed, one must verify that this reservoir model is consistent with all available information and interpretation models.**

  This means that the reservoir model must reproduce all data acquired:

  - ➔ **the seismic,**
  - ➔ **logs, etc...,**
  - ➔ **well tests.**


Data type 1
Data type 3
Data type 3
Identification
Identification
Identification
Consistency Verification
NO
Consistency Verification
NO
Consistency Verification
NO
YES
YES
YES
Interpretation Model for Data Type 1
Interpretation Model for Data Type 2
Interpretation Model for Data Type 3
Integration into Reservoir Model
Simulate Data Type 1
Simulate Data Type 2
Simulate Data Type 3
Match Data Type 1
NO
Match Data Type 2
NO
Match Data Type 3
NO
YES
YES
YES
NO
RESERVOIR MODEL

VERIFICATION OF RESERVOIR MODEL FLOW BEHAVIOUR



RESERVOIR MODEL FLOW BEHAVIOUR

- **USUALLY APPROXIMATED WITH NUMERICAL SIMULATOR**
- **DIFFERENT FLOW SIMULATORS MAY BE REQUIRED FOR DIFFERENT FLOW DATA**
  - **COMPLEXITY OF SIMULATOR FUNCTION OF PERFORMANCE TO BE SIMULATED (Black Oil, Compositional, Thermal, Chemical)**
  - **WELL TEST DATA REQUIRE HIGH RESOLUTION NEAR WELLS**
  - **GRIDDING FOR EXISTING NUMERICAL SIMULATORS COARSER THAN FOR RESERVOIR MODEL (UPSCALING REQUIRED)**
  - **SIMULATION OF VERY LARGE RESERVOIRS OR OF LOCAL HETEROGENEITIES REQUIRES:**
    - **Several hundred thousand cells, or**
    - **New mathematical formulations (Adaptive gridding, Streamline simulators,....)**

RESERVOIR MODEL
FLOW BEHAVIOUR VERIFICATION

- **RESERVOIR MODEL FLOW BEHAVIOUR CONSISTENCY IS VERIFIED BY COMPARING:**
  - **OBSERVED DATA FROM WELLS (GOR, WOR,...), and**
  - **CORRESPONDING RESPONSES FROM NUMERICAL SIMULATOR (HISTORY MATCHING)**
- **POSSIBILITY TO MATCH SATURATION FRONT LOCATIONS BETWEEN WELLS OBTAINED FROM REPEATED 3-D SEISMIC SURVEYS (RESERVOIR MONITORING)**

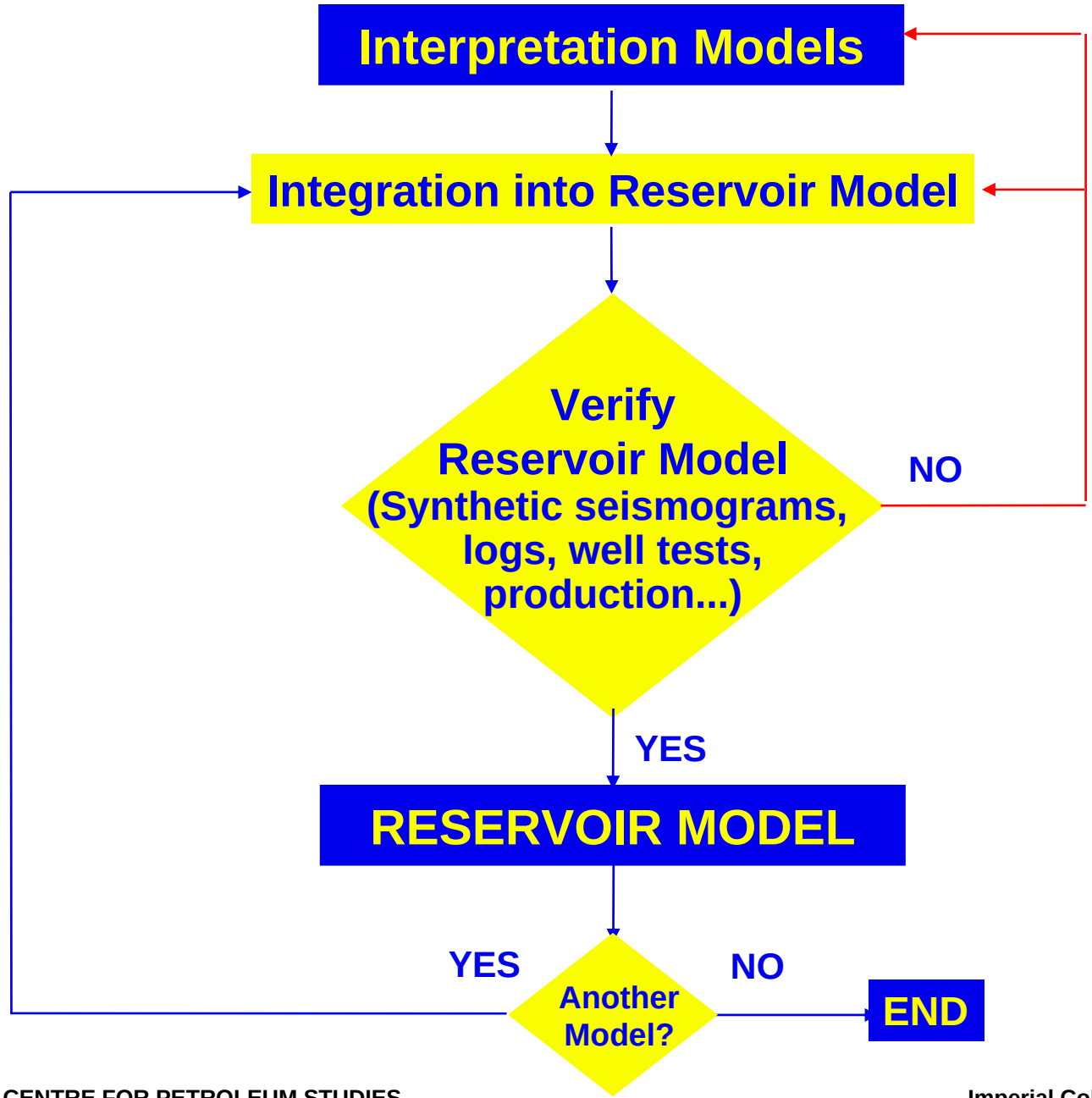
HISTORY MATCHING

- MATCH BETWEEN DATA AND MODEL CALCULATED BEHAVIOR CAN BE REFINED BY ADJUSTING RESERVOIR MODEL PARAMETERS WITHIN LIMITS CONTROLED BY CONDITIONING

- ADJUSTMENT CAN BE MADE EASIER AND FASTER WITH STATISTICAL OPTIMISATION METHODS (ADAPTIVE HISTORY MATCHING) AND EXPERT SYSTEMS

- LACK OF SATISFACTORY MATCH WITHIN LIMITS CONTROLED BY CONDITIONING REQUIRES MODIFYING THE RESERVOIR MODEL (RESERVOIR CHARACTERISATION)

CHARACTERISATION: AN ITERATIVE PROCESS

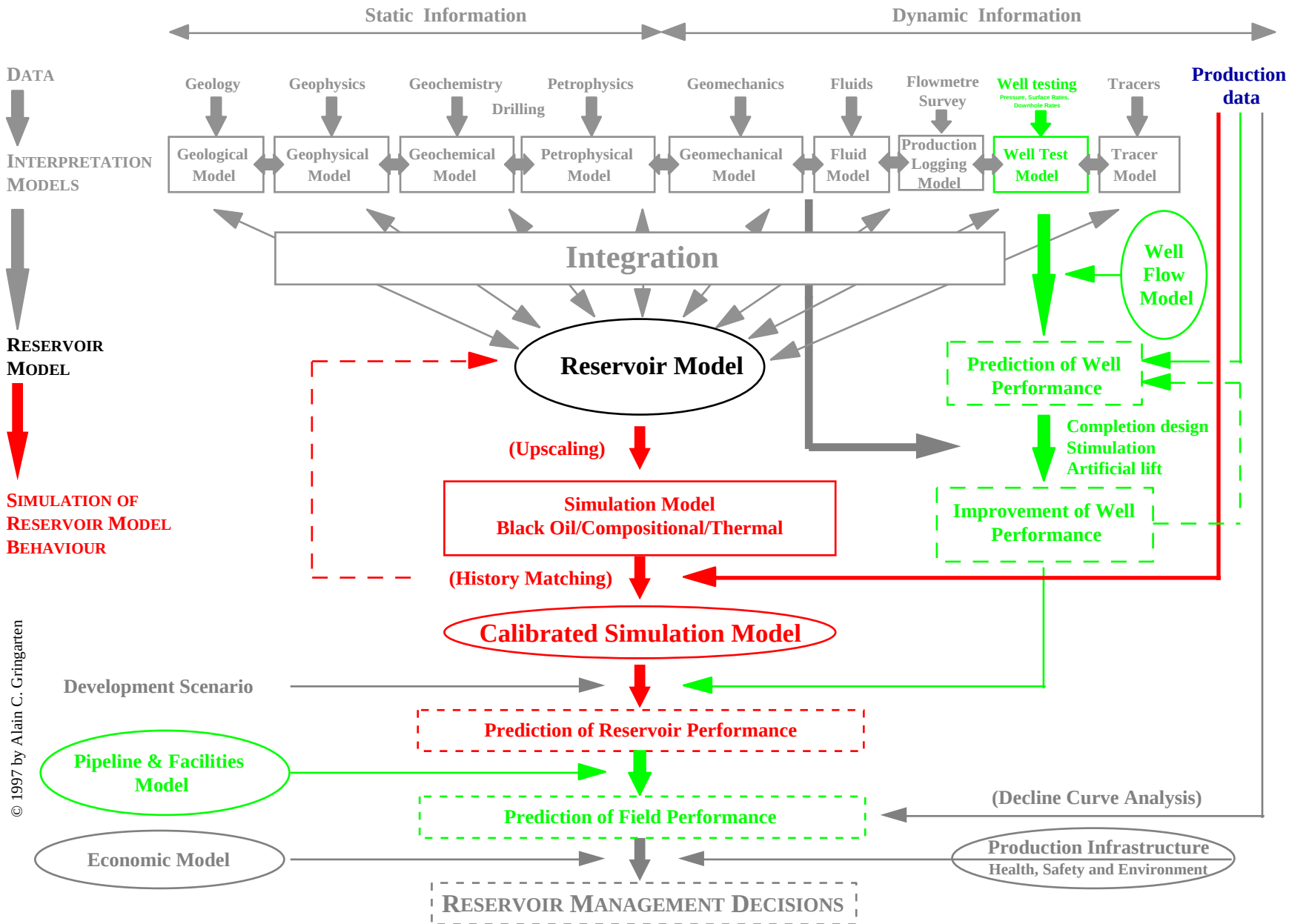


PRODUCTION PREDICTION

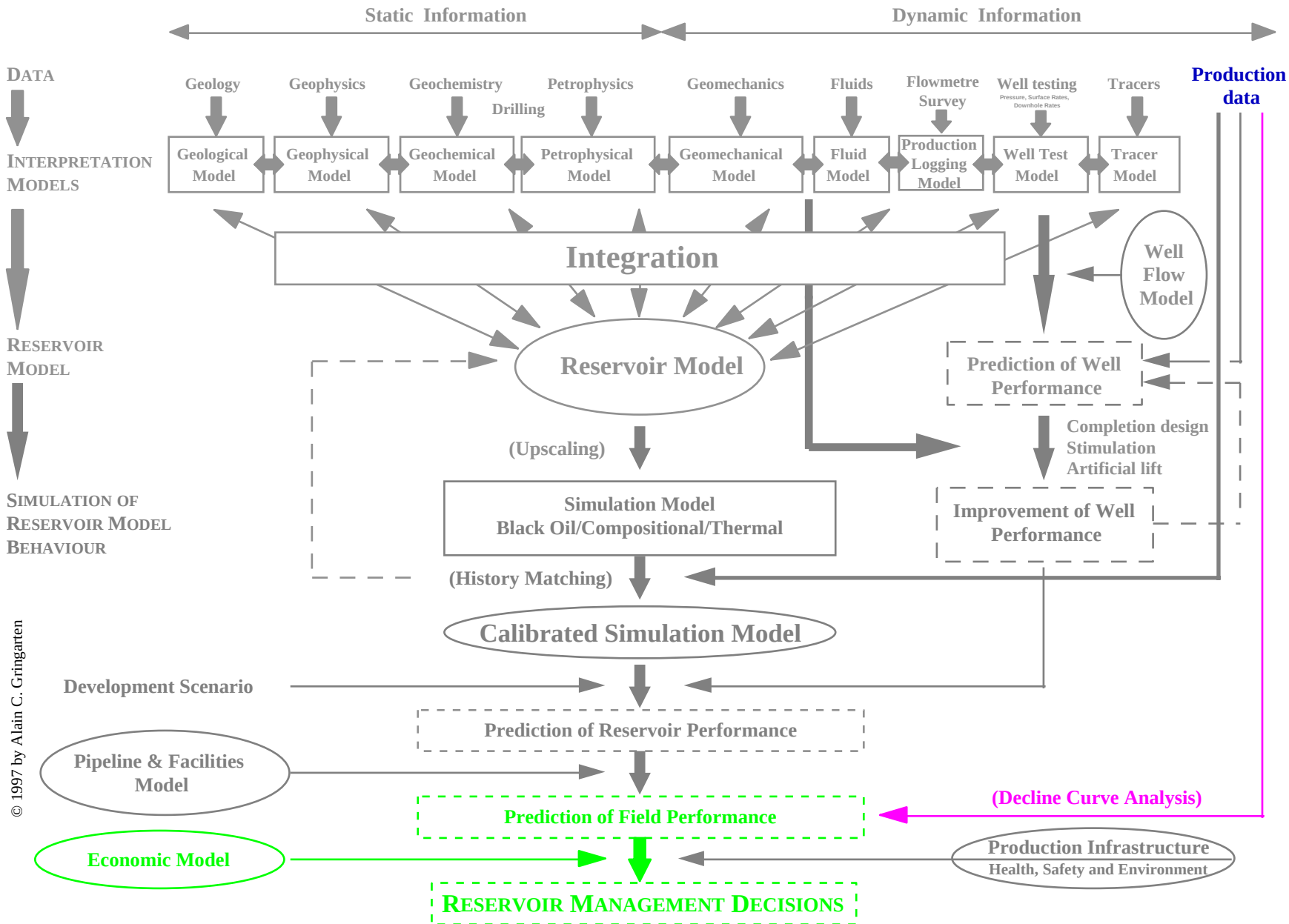
- **FOR PREDICTING PRODUCTION, THE RESERVOIR SIMULATOR MUST BE COUPLED WITH:**

  - ⇩ **WELL MODELS AND**
  - ⇩ **A SURFACE FACILITIES SIMULATOR**

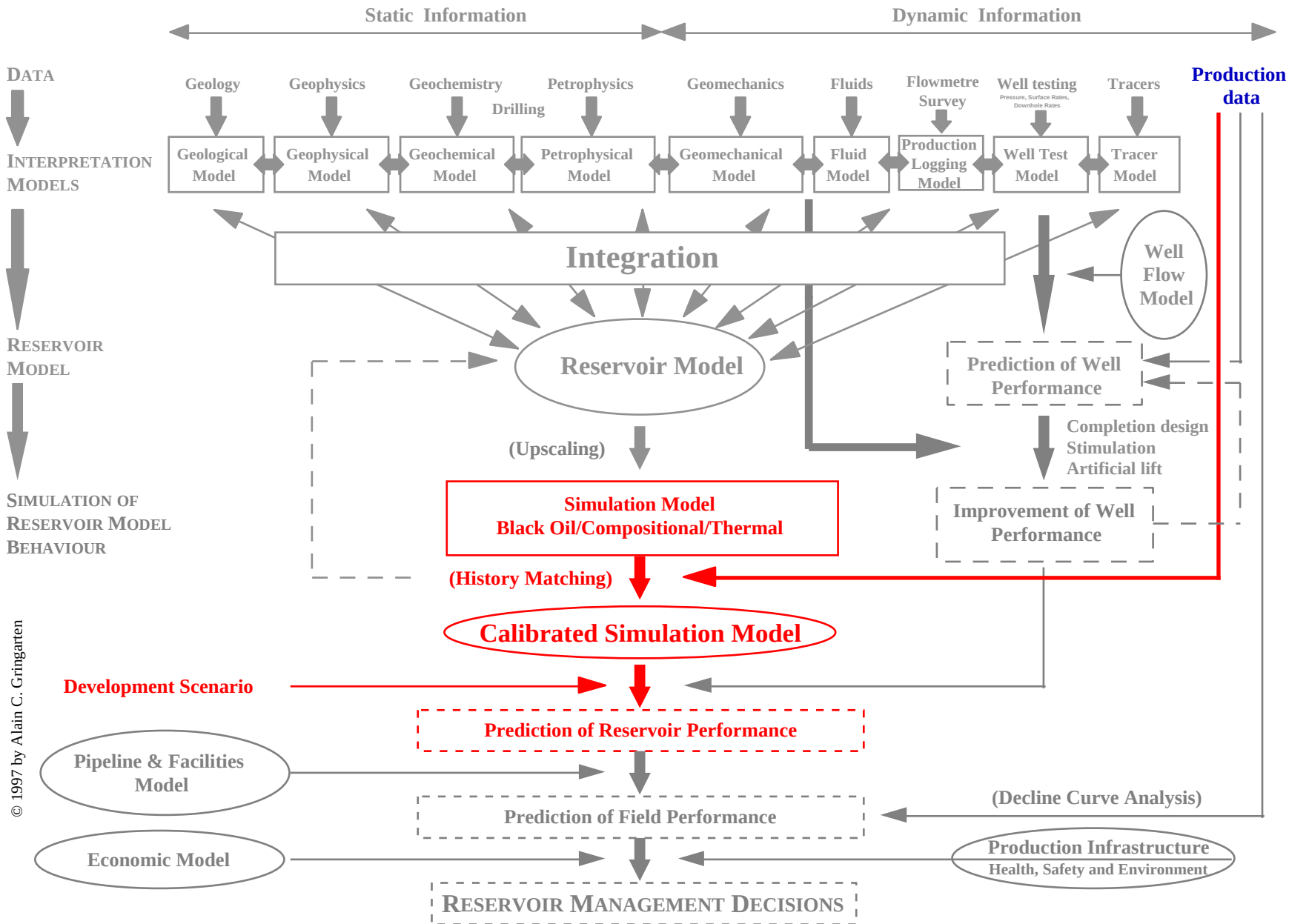
PRODUCTION PREDICTION



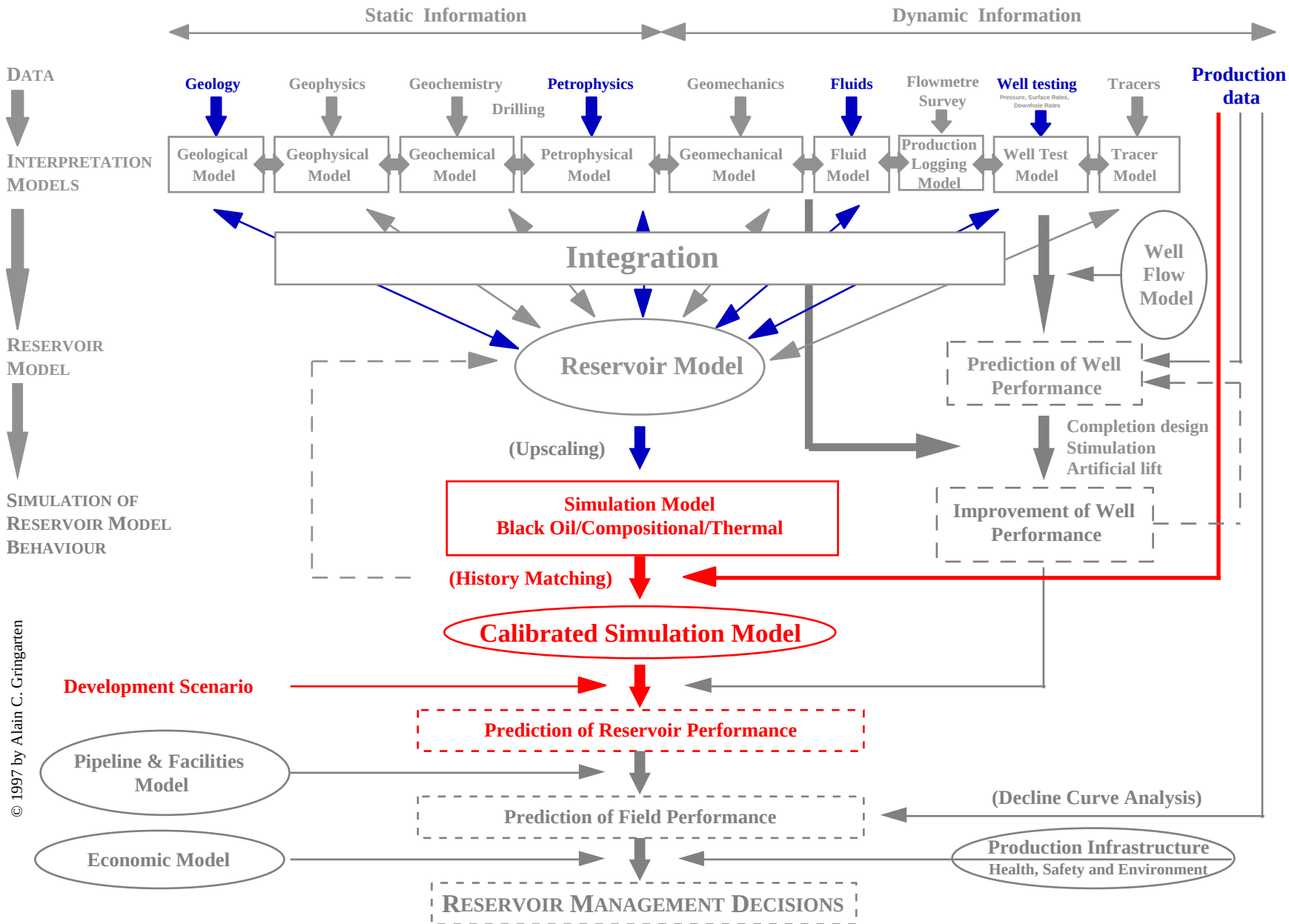
DECLINE CURVE ANALYSIS



RESERVOIR SIMULATION (1960's to 1970's)



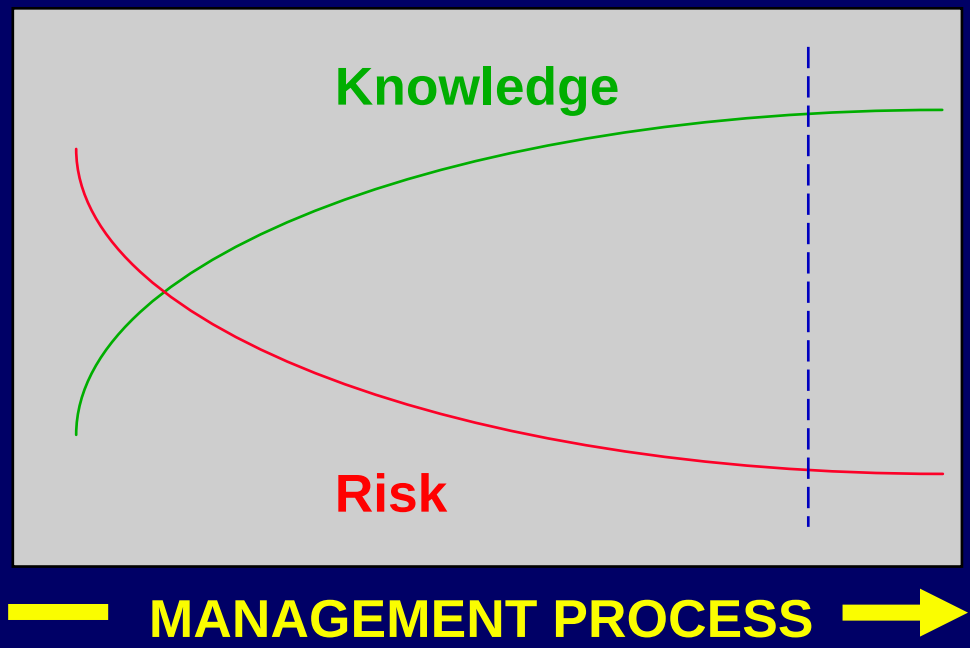
RESERVOIR SIMULATION (1980's)



FREQUENTLY ASKED QUESTION

HOW MUCH OF THIS PROCESS

DO WE NEED TO GO THROUGH?



NEED TO QUANTIFY THE RISK

IMPLEMENTATION THROUGH NEW TECHNOLOGY

- STOCHASTIC MODELLING
- ADAPTIVE HISTORY MATCHING
- RESERVOIR MONITORING
- NEW MATHEMATICAL FORMULATIONS FOR SIMULATORS
- MULTIPHASE PIPELINE SIMULATORS
- MASSIVE PARALLEL PROCESSING
- KNOWLEDGE BASE SYSTEMS
- COMPUTER AIDED PRODUCTION (CAP) TOOLS

COMPUTER AIDED PRODUCTION (CAP) TOOLS

- THE POWERFUL AND PROVEN COMPUTER TECHNOLOGIES
- THAT HAVE BEEN USED BY SPECIALISTS
- BEING MADE AVAILABLE TO AND USABLE BY THE PRACTISING PROFESSIONAL

NEEDS OF THE PRACTISING PROFESSIONAL

- **EASE-OF-USE**
- **PRODUCTIVITY**

➔ **TRANSPARENT TECHNOLOGY**

➔ **TASK ORIENTED APPROACH**

➔ **KNOWLEDGE BASED SYSTEMS**

➔ **METHODOLOGY (HENCE REPEATABILITY)**

CONTENT

- RESERVOIR MANAGEMENT PROCESS
  - DEFINITION
  - OBJECTIVES
  - METHODOLOGY
  - IMPLEMENTATION
- IMPACT ON COMPETITIVE ADVANTAGE
- PETROLEUM ENGINEERING CURRICULUM

COMPETITIVE ADVANTAGE

IF TOOLS BECOME STANDARD

- METHODOLOGY
- SOFTWARE

COMPETITIVE ADVANTAGE MUST BE

➔ THE UNDERSTANDING OF FUNDAMENTALS

➔ KNOW-HOW

Example: Well Test Analysis

WELL TEST ANALYSIS

BREAKTHROUGH IN THE 1980'S

- FROM INDIVIDUAL METHODS GIVING DIFFERENT ANSWERS TO AN INTEGRATED METHODOLOGY BASED ON SIGNAL THEORY
- WELL TEST ANALYSIS SOFTWARE
- PERSONAL COMPUTERS
- DIFFERENT INTERPRETERS USING THE SAME METHODOLOGY GET THE SAME ANSWERS

SIDE EFFECTS

➔ ERRONEOUS ANALYSES, FASTER

SOLUTION

➔ EDUCATION / TRAINING

CONTENT

- RESERVOIR MANAGEMENT PROCESS
  - DEFINITION
  - OBJECTIVES
  - METHODOLOGY
  - IMPLEMENTATION
- IMPACT ON COMPETITIVE ADVANTAGE
- PETROLEUM ENGINEERING CURRICULUM

NEW CURRICULUM

SPECIALISTS THAT KNOW HOW TO WORK EFFECTIVELY IN MULTI-DISCIPLINARY TEAMS

Fundamental Understanding of:

Reservoir Characterisation, Reservoir Modelling, Reservoir Simulation, and Field Management

The Processes for Integrating and Processing All Available Information in Order to Make Reservoir Management Decisions

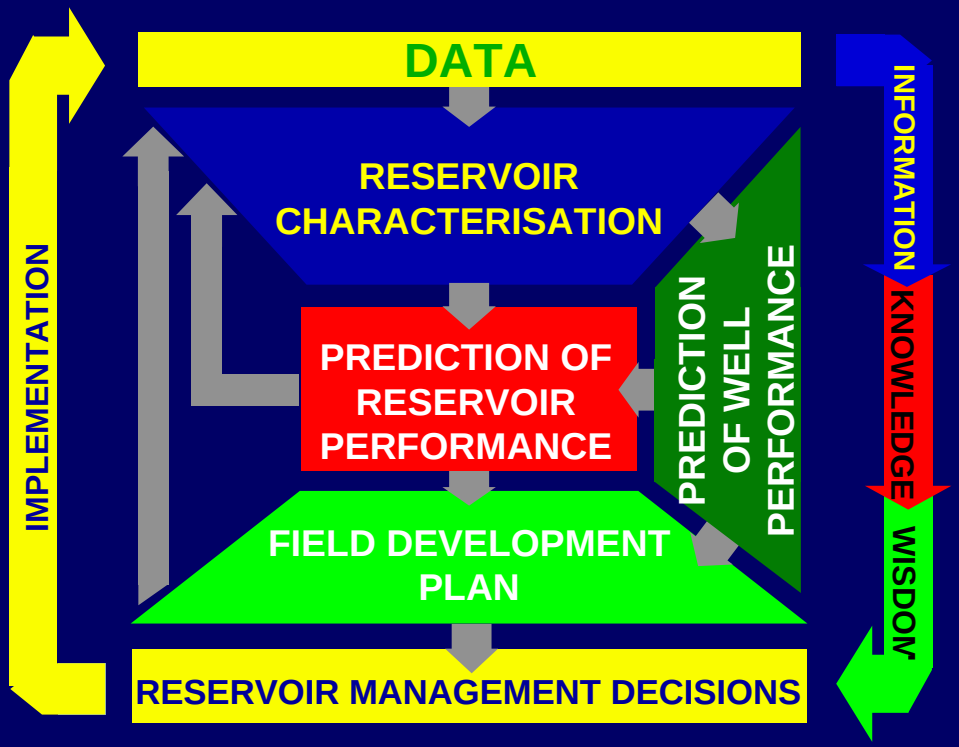
- ➔ **Work Flow Concepts**
- ➔ **Links Between the Various Types of Data**

MSc Specifications

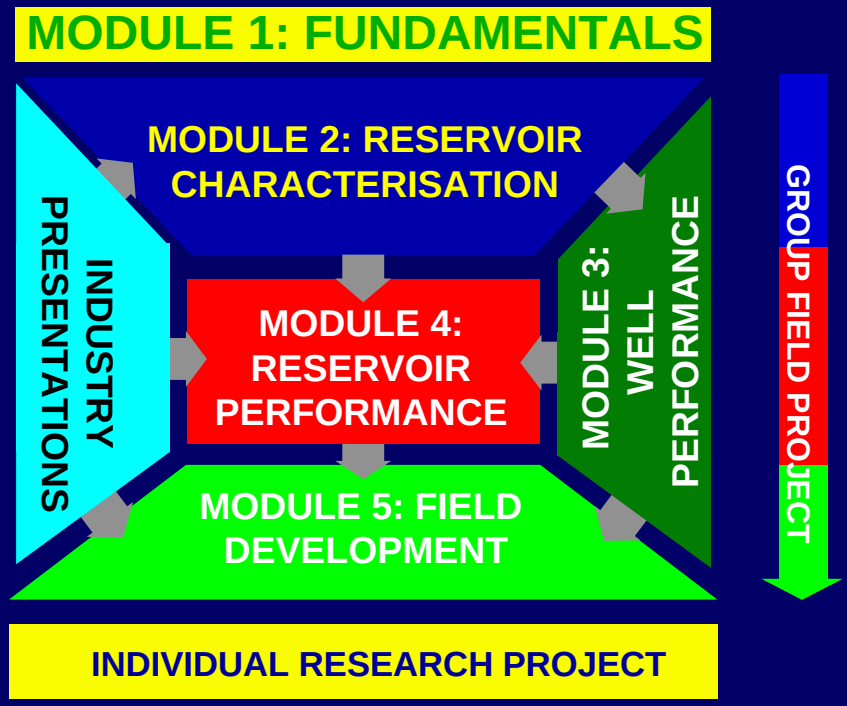
- Follow the reservoir management process

EXAMPLE:
THE MSc IN PETROLEUM ENGINEERING AT IMPERIAL COLLEGE

THE RESERVOIR MANAGEMENT PROCESS



THE MSc IN PETROLEUM ENGINEERING



MSc Specifications

- Follow the reservoir management process
- Lectures only by experts in their fields

MSc Specifications

- Follow the reservoir management process
- Lectures only by experts in their fields
- Students with fundamental background

MSc Specifications

- Follow the reservoir management process
- Lectures only by experts in their fields
- Students with fundamental background
- Fundamental / Application / Support courses

October

November

December

FUNDAMENTALS 103 hrs

Introduction

Basic Petroleum Geology

Basic Petroleum Geophysics

Rock properties

Sub-Surface Mapping

Reservoir Fluids

Hydrocarbons in-place and Reserves

Production Mechanisms

Flow In Porous Media

Drilling

Introduction to petroleum economics

RESERVOIR CHARACTERIZATION 183 hrs

Geological, geophysical and geochemical modeling

Geomechanics

Petrophysics

Production logging

Fluid sampling and analysis

Well Testing

Integration into reservoir model

Group Project Phase 1:
Reservoir Characterization

WELL 42

Well completion practices

Principles of well production

RESERVOIR PERFORMANCE 114

Reservoir Performance prediction

Numerical Reservoir Performance predictors

Upscaling

Practical use of numerical simulators

History matching, predictions and optimisation

Group Project Phase 2:
Predictions and Well Placement Optimization

FIELD DEVELOPMENT 96

Process engineering/surface facilities

Extending field life and improved oil recovery

Health, safety and environment

Economics

Group Project Phase 3:
Surface Facilities and Development Plan

January

February

March

EXAMS

Early May

INDIVIDUAL PROJECT

May to September

MSc Specifications

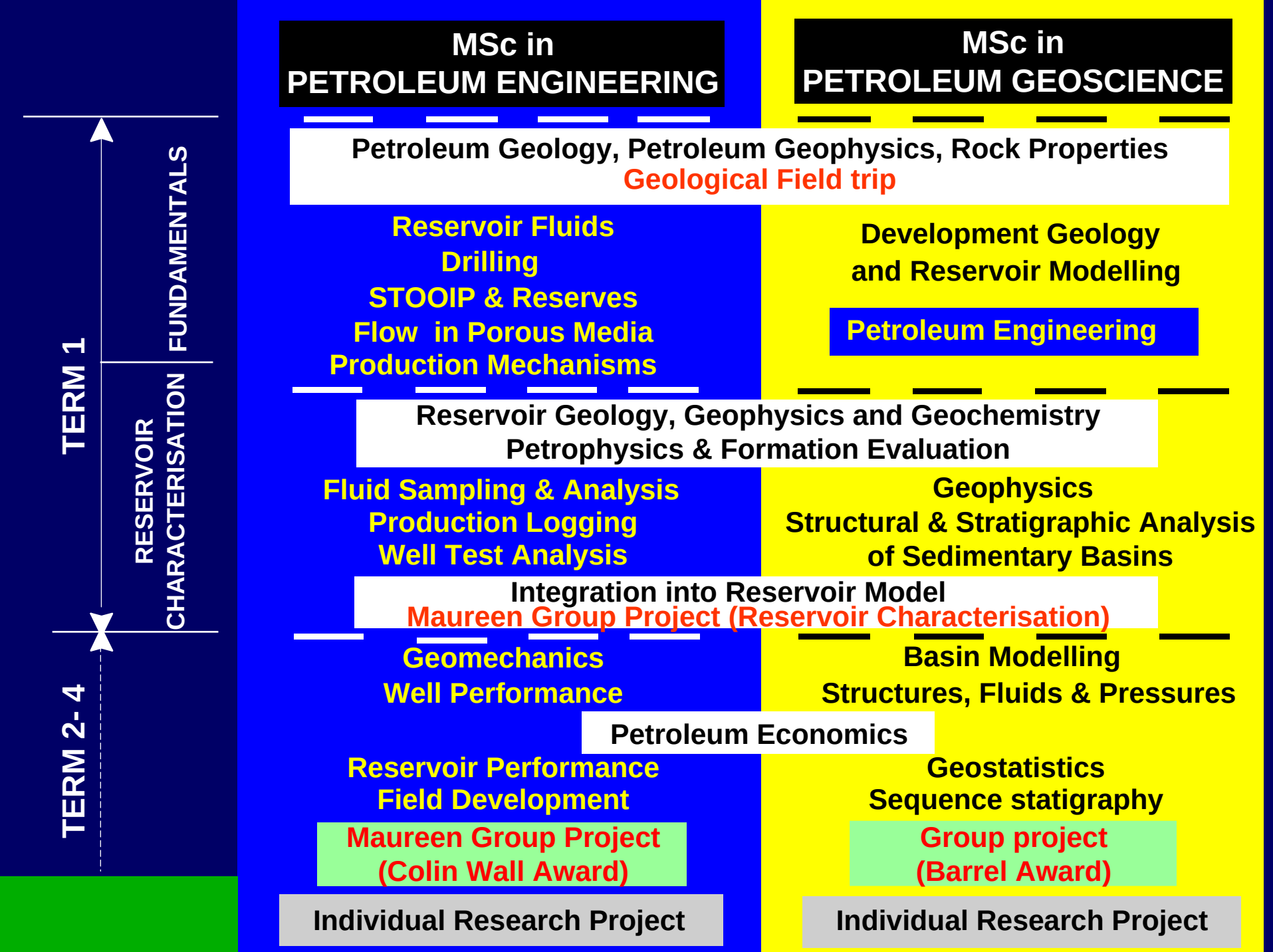
- Follow the reservoir management process
- Lectures only by experts in their fields
- Students with fundamental background
- Fundamental / Application / Support courses
- Block teaching

MSc Specifications

- Follow the reservoir management process
- Lectures only by experts in their fields
- Students with fundamental background
- Fundamental / Application / Support courses
- Block teaching
- Lectures/notes coordinated and integrated

MSc Specifications

- Follow the reservoir management process
- Lectures only by experts in their fields
- Students with fundamental background
- Fundamental / Application / Support courses
- Block teaching
- Lectures/notes coordinated and integrated
- Integration with Petroleum Geoscience


MSc in
PETROLEUM ENGINEERING
MSc in
PETROLEUM GEOSCIENCE
TERM 1
FUNDAMENTALS
RESERVOIR
CHARACTERISATION
TERM 2- 4
Petroleum Geology, Petroleum Geophysics, Rock Properties
Geological Field trip
Reservoir Fluids
Drilling
STOOIP & Reserves
Flow in Porous Media
Production Mechanisms
Development Geology
and Reservoir Modelling
Petroleum Engineering
Reservoir Geology, Geophysics and Geochemistry
Petrophysics & Formation Evaluation
Fluid Sampling & Analysis
Production Logging
Well Test Analysis
Geophysics
Structural & Stratigraphic Analysis
of Sedimentary Basins
Integration into Reservoir Model
Maureen Group Project (Reservoir Characterisation)
Geomechanics
Well Performance
Basin Modelling
Structures, Fluids & Pressures
Petroleum Economics
Reservoir Performance
Field Development
Geostatistics
Sequence statigraphy
Maureen Group Project
(Colin Wall Award)
Group project
(Barrel Award)
Individual Research Project
Individual Research Project

MSc Specifications

- Follow the reservoir management process
- Lectures only by experts in their fields
- Students with fundamental background
- Fundamental / Application / Support courses
- Block teaching
- Lectures/notes coordinated and integrated
- Integration with Petroleum Geoscience
- Teach prevailing commercial software

MSc Specifications

- Follow the reservoir management process
- Lectures only by experts in their fields
- Students with fundamental background
- Fundamental / Application / Support courses
- Block teaching
- Lectures/notes coordinated and integrated
- Integration with Petroleum Geoscience
- Teach prevailing commercial software
- **Use actual field data**

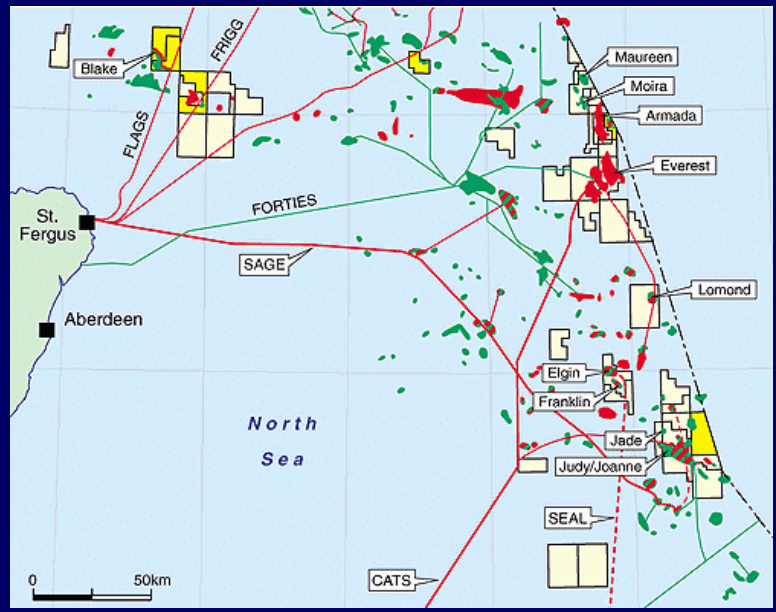
Use of field data

- Tutorials for taught courses
- Group field project
  - Phase 1: Reservoir characterisation
    16 teams (Petroleum Engineering+Geoscience)
  - Phases 2: Production planning
    8 teams (Petroleum Engineering)
  - Phase 3: Field development
    8 teams (Petroleum Engineering)
- Individual research projects

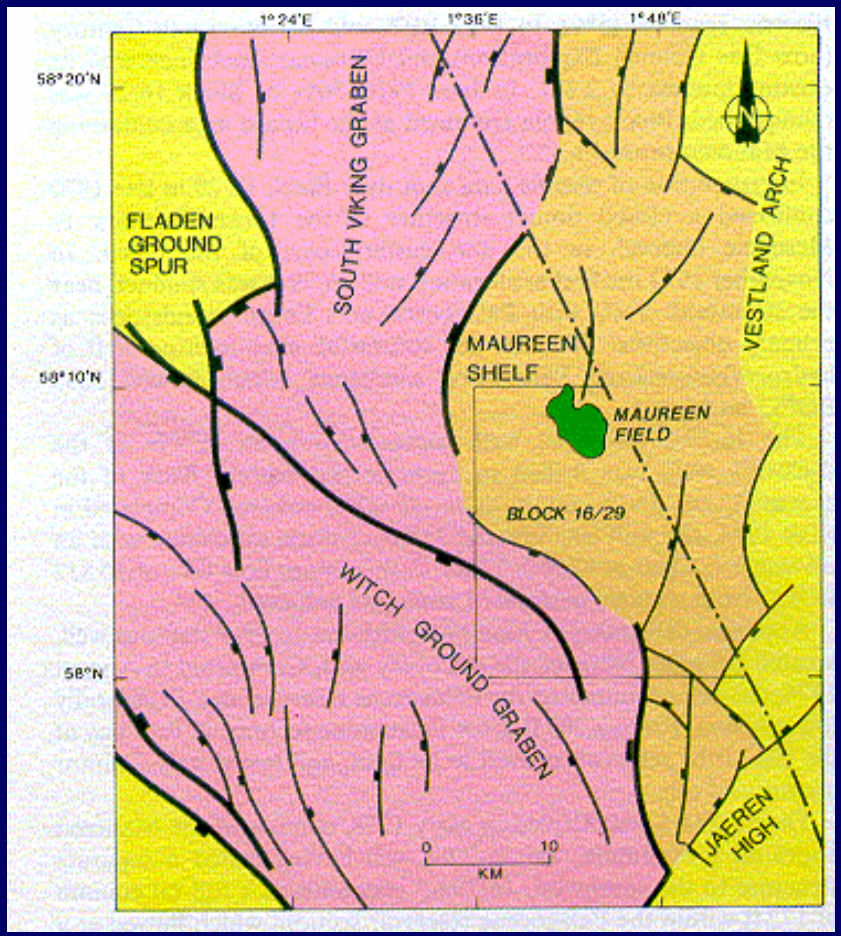
Field data: Maureen Field

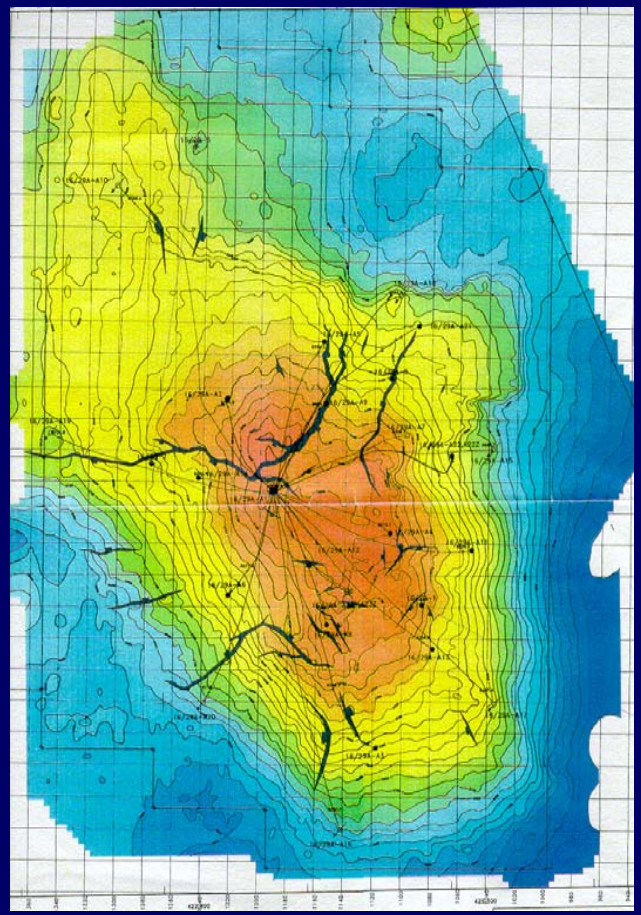
- Block 16/29a (UK sector of the North Sea)
- Phillips UK operator
- 1983-1999
- 4 appraisal,12 production and 7 water injection wells

seismic traces and interpreted maps; geological maps; core photographs; routine and special core analysis reports; PVT analysis reports; RFT data; DST and production test data; monthly production data



Field data: Maureen Field



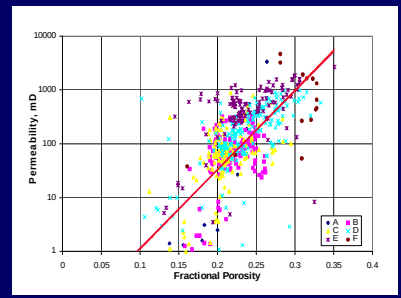


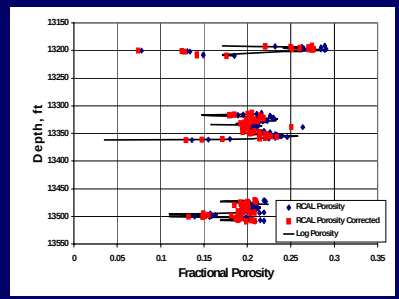
Maureen Group Field Project

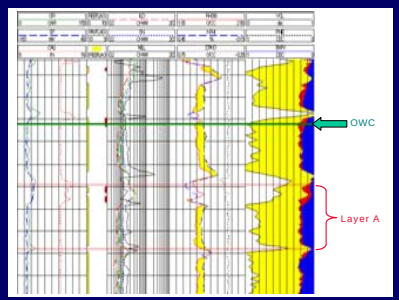
Phase 1: Reservoir characterisation

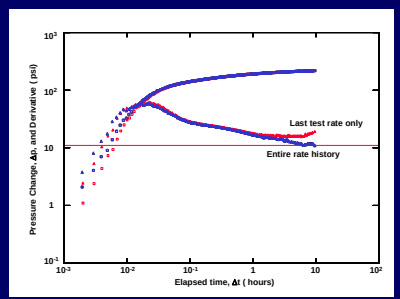
10 days, December

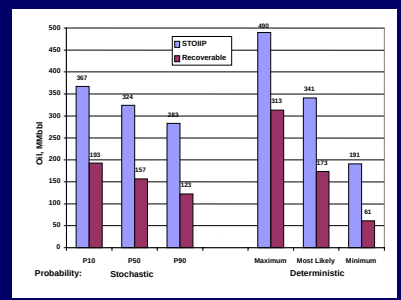
- 5-6 wells
- STOIIP
- Reserve estimates
- Preliminary 3D model

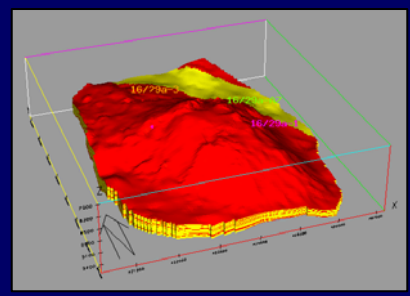










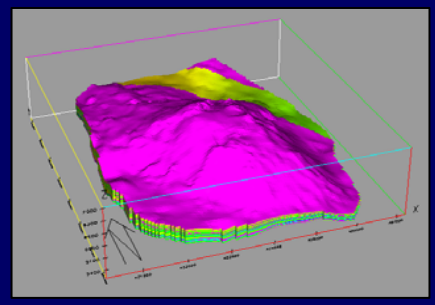


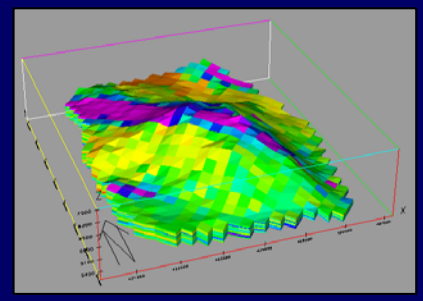
Maureen Group Field Project

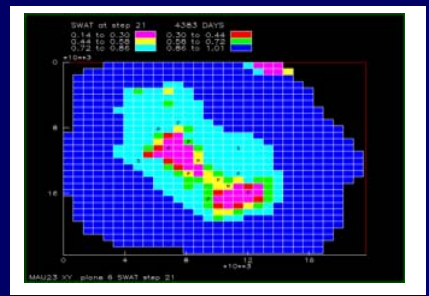
Phase 2: Well placement & Production Optimization

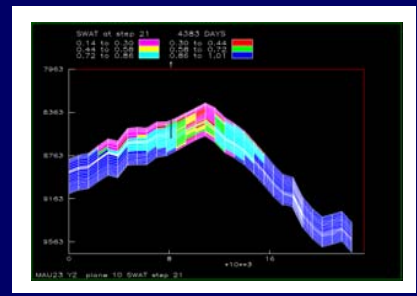
6 days, February

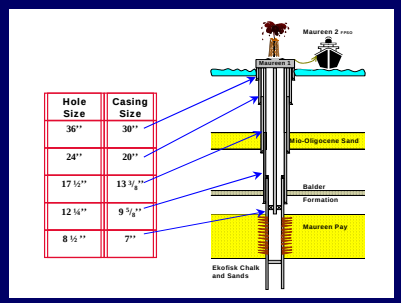
- simulation model
- optimized well placement plan
- oil recovery
- cumulative oil production
- optimized well design
- artificial lift options
- a drilling plan
- casing design

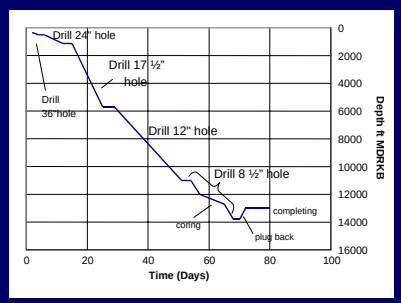


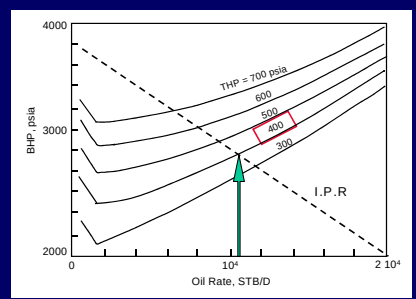


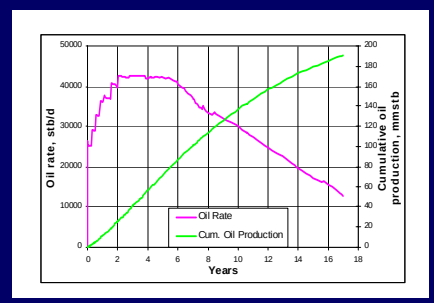










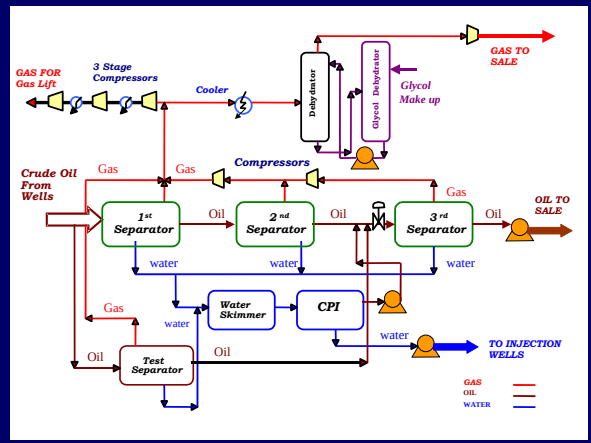


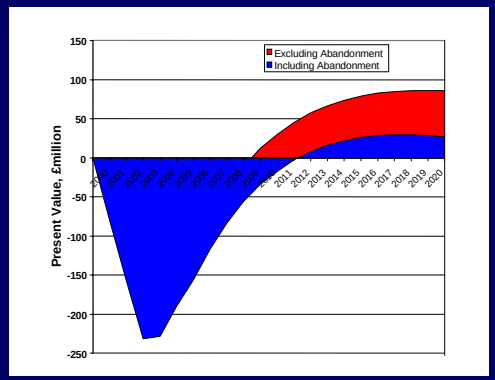
Maureen GroupField Project

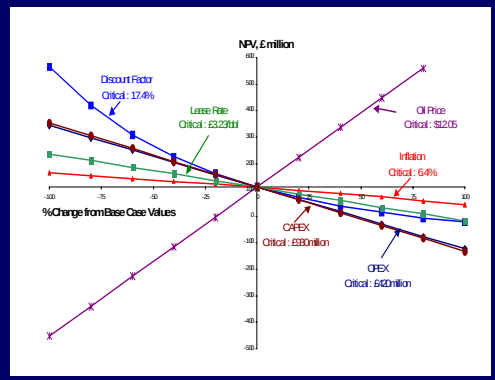
Phase 3: Development plan

10 days, March

- improved recovery plan
- surface production facilities
- HSE plan
- economic viability
- abandonment plan
- assessment of risks
- Colin Wall prize







THE ULTIMATE RESERVOIR MANAGEMENT GOAL

- TO MODEL A PETROLEUM RESERVOIR AND ASSOCIATED WELL AND SURFACE FACILITIES WITH SUCH AN ACCURACY
- THAT ON-GOING PREDICTIONS CAN BE USED WITH CONFIDENCE TO OPTIMISE PRODUCTION OPERATIONS, INCREASE RECOVERY AND REDUCE OPERATING COSTS
- THEREBY SUBSTANTIALLY INCREASING ECONOMIC RETURN WITHIN MANAGEMENT GUIDELINES