MIGRATION OF HIGH Cl-B MOLAR RATIO, GAS-DEPLETED AND COOLER MASAKROT FLUIDS TOWARD THE CENTRAL PALAYANG BAYAN SECTOR OF THE BACMAN GEOTHERMAL PRODUCTION FIELD, PHILIPPINES

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Abstract

The migration of the high Cl-B molar ratio (70-80), gas-depleted (0.12 % NCG in total discharge) and cooler (240-250°C) Masakrot fluids toward the central Palayang Bayan sector of the Bacman geothermal production field is a result of pressure drawdown due to continuous exploitation. The recharge from Masakrot has minimised the decline of reservoir pressure (0.70 Mpag) in the southern sector wells (Sector IV) and has resulted in minimal reduction in power output of 2.7 MWe after 3 years of exploitation. However, the entry of Masakrot fluid has no impact yet on the NCG level of the field because affected wells are already low in gas. Unaffected wells remain gassy and are producing from the gas-rich two-phase upper feed zones. The Masakrot fluid is conveyed to Pal-3D and Pal-1D mainly through the Bayan South fault. The next wells that may be affected by Masakrot fluids through the Makabug and Madanan faults could be the wells in the northern (sector I) and central sectors (Sector III) where the Cl-B molar ratios are already increasing close to the Masakrot fluid signature. Significant decline in gas levels may follow and alleviate the high NCG problem in Bacman I. The 12 MWe decline in power output from October 1995 to December 1996 is not related to Masakrot fluid incursion, but can be attributed to: 1) large pressure drawdown in Pal-8D (6.3 MWe) and Pal-20D (3.2 MWe) and 2) cooler water inflows due to casing damage in Pal-14D (2.1 MWe).

1.0 INTRODUCTION

Since the start of commercial exploitation of the Bacman geothermal production field (BGPF) in 1993, the major chemical change observed was the continuous decline in the boron content in most of the production wells. This has resulted in the increase of the Cl-B molar ratios. This phenomenon has been attributed to the migration of fluids from the Masakrot sector towards the central Palayang Bayan producers as induced by pressure difference between the two regions due to exploitation. The discussions are focused on the response to exploitation of the wells in the four production sectors in Bacman-I (Fig. 1).

The BGPF integrated geochemical field model (Solis, et al., 1994) suggests a unique chemistry for the Masakrot fluid. (Fig. 2). This fluid serves as a natural recharge to the system and is characterized by a high Cl-B molar ratio of 70-80, with temperature range between 240-250°C and low CO_{2TD} of 50 mmol/100mols H_2O (0.12 % NCG in total discharge) and is closely represented by Pal-5D reservoir fluids.

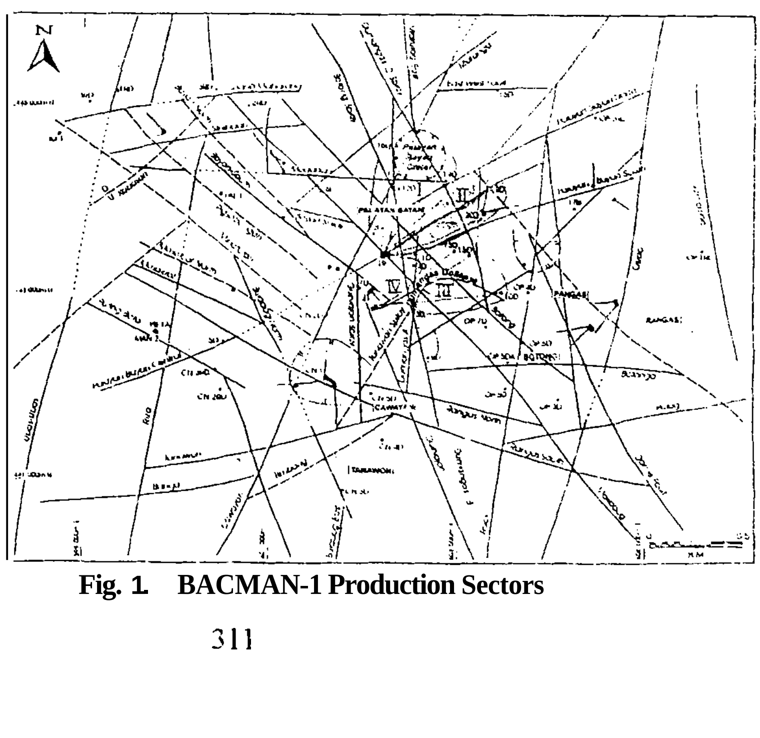

Fig. 1. BACMAN-1 Production Sectors

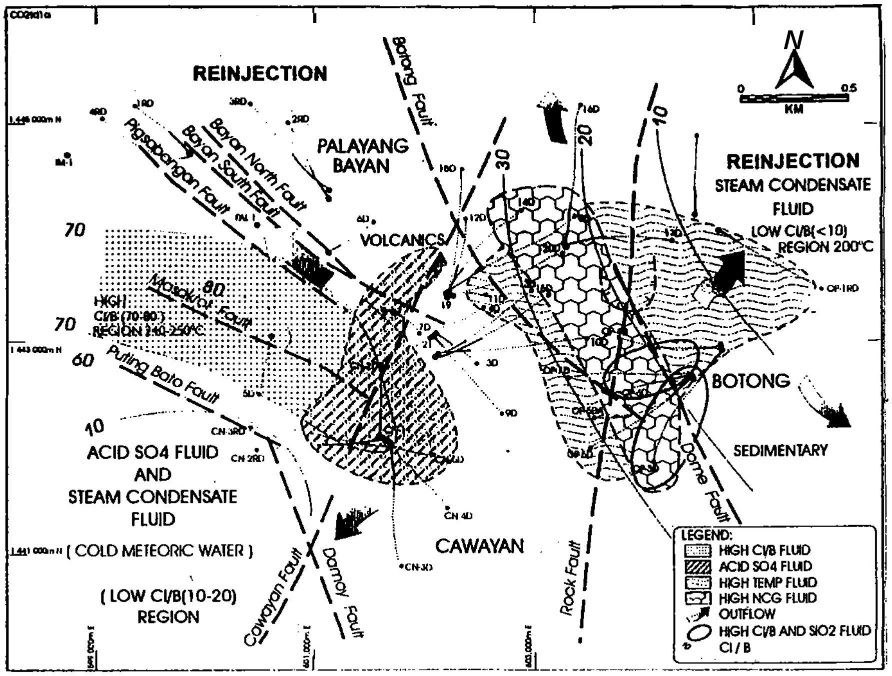

Fig. 2. BGPF Baseline Field Model

This report aims to 1) trace and characterize the Masakrot fluid migration, **2)** identify the geologic ***structures*** important to its flow regime, and 3) identify its **effects** on the field ***steam*** availability.

2.0 FIELD TRENDS

2.1 Iso-Cl-B Molar Ratio Contours

The **most** prominent chemical change in Bacman I is the decline in B contents of most wells across the field. **This has** resulted in increases in **Cl/B ratios** most prominently in wells Pal-3D and Pal-4D (Fig. 3). The Cl-B molar **ratio serves as a** natural tracer of fluid migration since it showed a wide variation across the field ranging from 10 to 80. The decline in B levels with time is related to the movement of the in-place B-depleted fluid from the western region of Masakrot to the central Palayang Bayan region. The migration of the Masakrot fluid is traced **by** the direction of the iso-Cl/B contours, with much higher values now skewed towards the Palayang Bayan production wells (Solis et **al., 1997).**

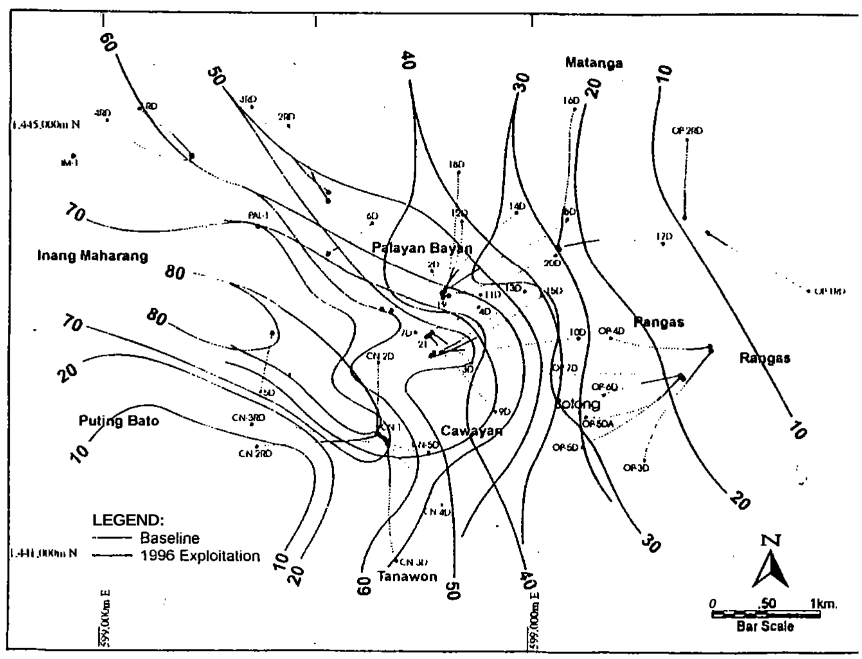

Fig. 3. ISO/Cl/B Molar Ratio Field Contour Exploitation

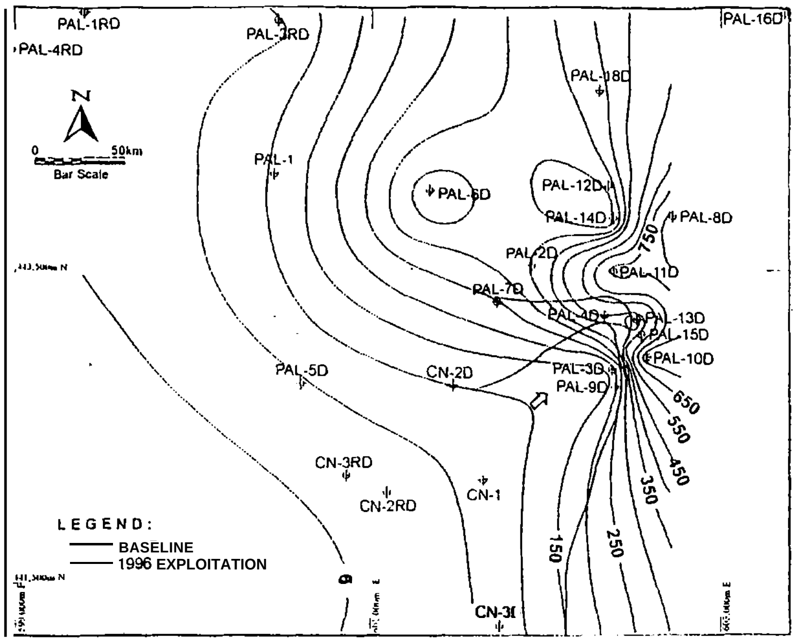

Fig. 4. CO_2 TD Field Trend

2.2 Iso-CO_{2TD} Contours

The change in the Cl/B contour is also reflected by the CO_{2TD} contours (Fig. 4). The contours indicate an elongation of the low-gas from the west towards the east into wells Pal-3D and Pal-4D. This is interpreted to be a consequence of the movement of the gas-depleted Masakrot fluids into Sector IV wells. These wells, however are already low in gas content and has minimal effect on the high NCG levels at the Bacman-I interface.

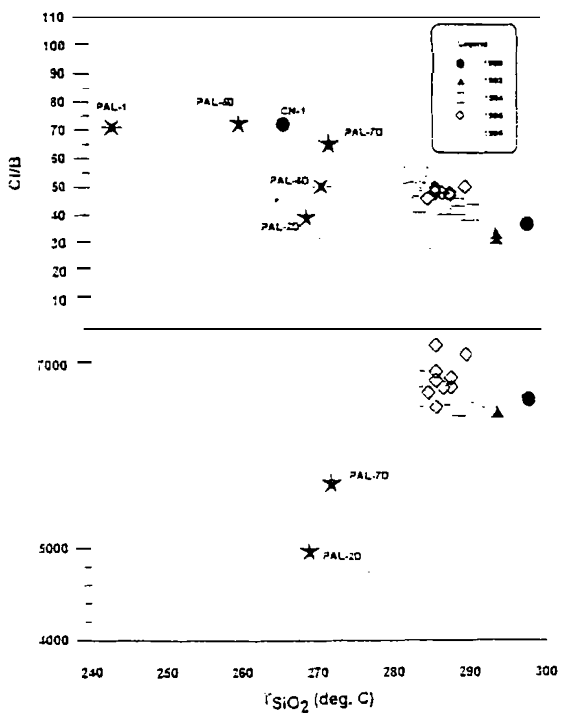

Fig. 5. Cl/B and Cl_{res} vs. $TSiO_2$ Plot for PAL-14D

2.3 Bacman-I Weighted Average NCG

The weighted average % NCG at the interface does not decline with time. The apparent lowering of the % NCG in 19% was just a consequence of cutting-out of high NCG wells (e.g. Pal-10D) and preferential well utilization to get the right well combination to meet the interface contract limit under low-load conditions of the power plant (Solis et al., 1996).

2.4 Bacman-I Field Output Trends

The field enthalpy has been consistently rising from 1993 to the third quarter of 1996. This was accompanied by increasing mass flows and steam flows as most wells experienced pressure drawdown and produced from the steam-rich upper feed zones. From October 1995 - December 1996, there was an apparent decline in the field enthalpy, accompanied by declining mass flows and *steam* flows. The total Bacman-I steam availability within this period was reduced from 50.0 kg/s to 47.4 kg/s or a decline in power output from 134 MWe to 122.5 MWe. The 12 MWe decline, however, was not accompanied by any large increases in waterflows as usually observed when injection returns pervades the production wells. Geochemical data further confirms the absence of reinjection fluid returns in the production sector. This raised concern on the likely cause of the steam decline and measures to arrest or mitigate the problem (Gerona, et. al., 1997).

3.0 PHYSICAL AND CHEMICAL CHANGES

3.1 Sector I (Pal-12D, -14D, -18D, 19)

The discharge enthalpies of wells in this sector ranges from 1200-1350 kj/kg. Pal-12D and Pal-18D increased while that of Pal-14D and Pal-19 declined with time. This sector has a moderate pressure drawdown of 1.74 MPag as measured at Pal-18D. The decline in TMF and SF in Pal-14D reduced the *steam* availablity by 15.1 kg/s (or 6.9 MWe from 1994), the biggest decline recorded among all sectors.

There were chemical changes observed in this sector especially for the 13°C decline in T_{SiO2} of Pal-14D. The thermal decline is due to the cooler fluid inflow probably through the casing damage at 1618 mMD. Pal-14D has recorded a power output decline of 5.6 MWe. *An* alternative explanation for the output decline is the influx of a relatively cooler gas-depleted fluid, although the only clear signature of Masakrot fluid migration into this sector is the continuously increasing Cl-B molar ratios. Figs. 5 and 6 show the cross plots between Cl-B molar ratios against TSiO2 and CO2TD against CO2/H2S ratios, respectively. The decline in the CO2TD with the corresponding decline in the CO2-H2S ratio in 1996 (Fig.6) may suggest a possible mixing with the cooler gasdepleted fluids. This fluid may inflow at the depth of 'the casing damage and may not be necessarily from Masakrot. Gas equilibrium calculations using the FT-HSH diagram also support the signature of the migrating cooler fluids which may be similar with that of the Masakot-type. To date, Masakrot fluids has not totally reached Pal-14D except that indicated by the gas chemistry.

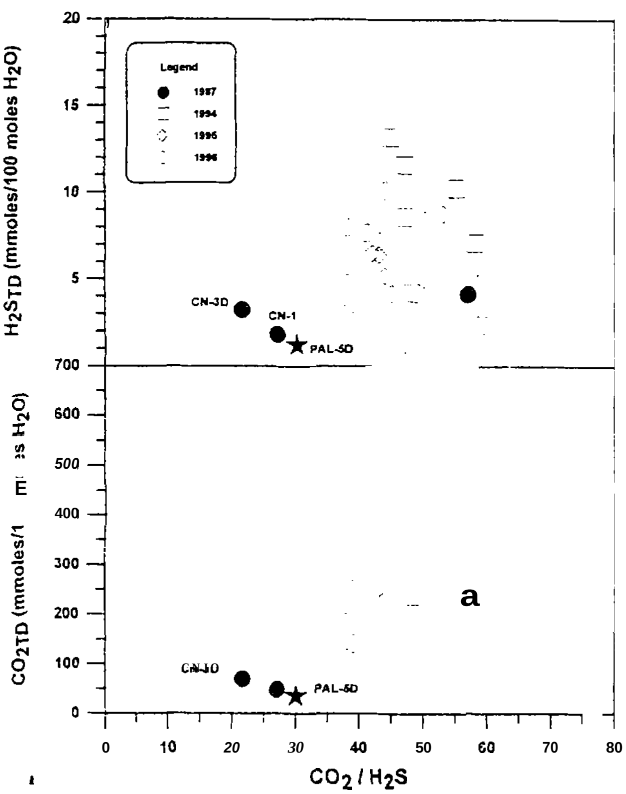

Fig. 6. H_2S_{TD} and $Co_{2\,TD}$ vs. CO_2/H_2S Plot for PAL-14D

With the present high Cl-B molar ratio values in this sector, it is projected that Sector I wells will receive a full migration of the Masakrot fluids within three years, assuming the present rate of pressure drawdown in this sector is maintained.

3.2 Sector II (Pal-8D, -20D)

This sector consistently show increasing discharge enthalpy trends from 1600 to 2100 kj/kg due to pressure drawdown. The highest pressure drawdown for the whole field measured from Pal-8D was at 3.77 MPag.

The pressure drawdown with minimal recharge caused a significant T_{SiO2} decline in Pal-8D (12°C) and Pal-20D (9°C), with a consequent drop in power output of 6.2 MWe for Pal-8D and 3.3 MWe for Pal-20D. These wells show the absence of Masakrot fluid signatures.

Gas equilibrium calculations with T_{SiO2} trends show the dominant steam discharge of Pal-8D with time and decline in temperatures due to pressure drawdown (Fig. 7). Prior to field exploitation, Pal-8D was drawing fluid partly from the liquid-dominated reservoir. With continued field drawdown, significant contribution comes from the *steam* dominated discharge which is presently being diluted by a relatively cooler, gas-depleted and dilute fluid. Presently, a study is being conducted to identify the source of this fluid.

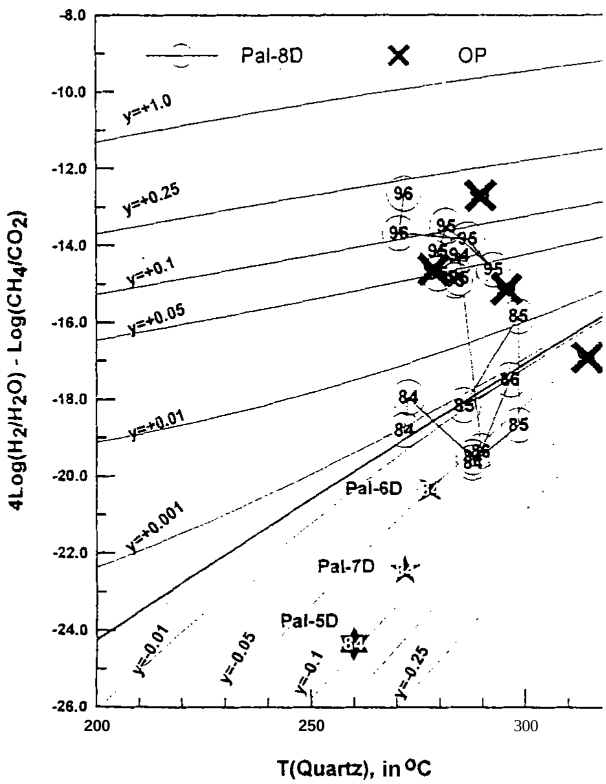

Fig. 7. Sector II FT-TSiO$_2$ Diagram

3.3 Sector III (Pal-10D, -11D, -13D, -15D)

This sector showed consistently rising enthalpy with time but with increasing steam availability. There is no downhole pressure measurement available but the H_{TD}, TMF and SF data are consistent with dominant pressure drawdown trends. This is also substantiated by the declining measured water level of Pal-10D with time.

Gas equilibrium calculations with quartz geothermometry show *steam* dominated discharges for wells in this sector (e.g. Pal-10D, -11D, -13D, -15D) but without the significant temperature declines shown by Sector II wells. This may be due to hot recharge to these wells, probably from the deeper feed zones.

Pal-13D show **significant** T_{SiO2} decline by 17°C (Fig. 8). This may be due to the blockage at 2353 mMD which resulted in the dominance of the highly two-phase upper **feed** zones. **Thus,** power output for **Pal-13D** remained stable with time.

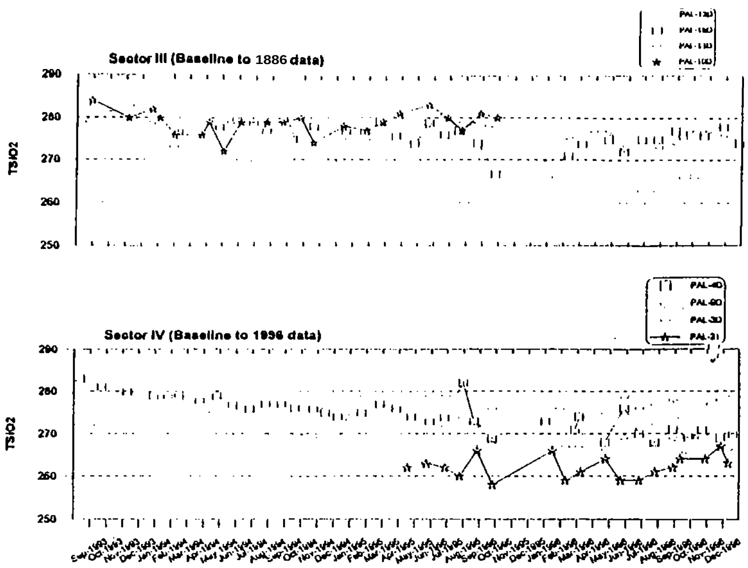

Fig. 8. TSiO$_2$ Field Trends (Sectors III & IV)

There is no definite **signature** of Masakrot fluid migration into **this** sector except for the continuously increasing Cl-B molar ratios (Fig. 9).

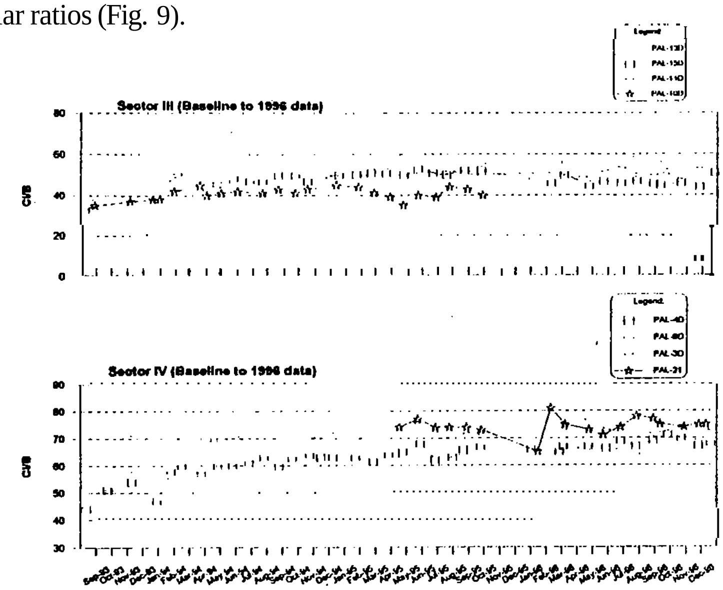

Fig. 9. Cl/B Field Trends (Sectors III & IV)

3.4 Sector IV (Pal-3D, -4D, -9D, -21)

There is **a** slow **gradual** decline in enthalpy **from 1300-1400** kj/kg **to 1200-1300** kj/kg **with** time. **This** is **reflected** in the declining T_{SiO2} temperatures of **Pal-3D and Pal-4D** (Fig. **8)** which is consistent with inflow of **a** cooler watery recharge fluid from **Masakrot.** This is also shown in the increasing Cl-B molar ratios from 40-***50* to 65-80** with exploitation (Fig. 9). The much higher T_{SiO2} **decline in Pal-4D may also be** attributed to the **inflow** of **a** relatively cooler fluid, which had been identified during the preexploitation **period, through** the casing break ***at*** **1281 mMD**.

Gas equilibrium calculations for Pal-3D and Pal-4D show a continuous change in the gas chemistry of the fluids to values proximate to Pal-5D or the representative Masakrot fluid signature. The CO_{2TD} values (100-200 mmol/100 mol H_2O) for these wells, however, did not decline further. This is because Pal-3D and 4D are already low in gas, hence the negligible gas decline. Only Pal-9D showed increases in gas content among the wells in this sector. This is because Pal-9D is the only well targeted east and the source of gas may be of deeper origin from the eastern sector of the field which is relatively gassy (Fig. 1).

The recharge from Masakrot in this sector has resulted in stable reservoir pressures with minimal drawdown of 0.70 MPag measured at Pal-3D. Among all sectors, this has the least reduction in power output pegged at 2.7 MWe.

4. POSSIBLE STRUCTURAL CONDUITS OF MASAKROT FLUIDS TO PALAYANGBAYAN SECTOR

The flow path of Masakrot fluid towards Palayang Bayan is controlled mainly by permeable faults. The major structural conduit is the northwest-trending Bayan South fault which directly connects Masakrot area to the southern sector (IV) of Palayang Bayan where effects of the Masakrot fluid migration are most evident.

From Bayan South fault, the fluids are dispersed to Sector IV wells through their fault intercepts which are directly linked to Bayan South. Thus, the Masakrot fluids are entering the major aquifer of PAL-4D through Dumangas B; and the main permeable zone of PAL-3D through Dumangas B and Tanawon Splay (Fig 10). In PAL-9D, the fluids are invading its main feed zone via Guinlajon and Dumangas A; while in PAL-21, they inflow along Bayan South, Guinlajon and Guinlajon Splay.

The wells in the central sector (III) of Palayang-Bayan exhibit less pronounced Masakrot fluid signatures in contrast to the southern wells (IV). In Sector III, the Masakrot fluids are possibly leaking to PAL-10D, 11D, 13D and 15D through their intersections with Dumangas A and/or Dumangas B. In addition, the northwest-trending Makabug fault also likely channels Masakrot fluids into PAL-11D although in smaller amounts in comparison to the major flow along Bayan South (Fig 10).

In the northwest sector (I) of Palayang-Bayan, the influence of Masakrot fluids is ambiguous. Though the observed, chemical changes in PAL-12D, 14D, 18D and 19D are attributed to cold fluid incursion, these cold fluids may not necessarily be derived from Masakrot area. Nonetheless, if Masakrot fluids are indeed migrating to northern Palayang-Bayan, the possible channels are Makabug fault which intersects PAL,-19, and Madanan fault which is connected to PAL-12D, 14D and 18D (Fig 10).

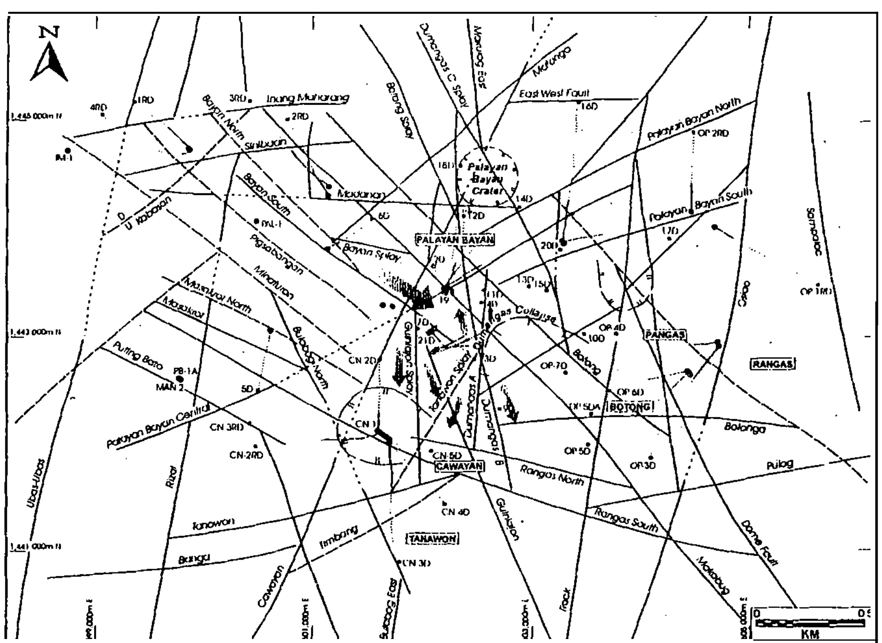

Fig. 10. Possible Flow paths of Masakrot Fluids

5. CONCLUSIONS AND RECOMMENDATIONS

The migration of the Masakrot fluid towards Palayang Bayan has been effective in slowing down reservoir pressure decline in sector IV. This has also resulted in the minimal reduction of power output in all sectors of the field. There has been no impact on the weighted field % NCG levels, because wells affected by the fluid migration are already gasdepleted. Other wells with high gas levels are now drawing gas-rich fluids from the two-phase upper feed zones because of the continuing pressure drawdown. These wells, are presently unaffected by the migration of Masakrot fluids.

The Masakrot fluid is conveyed to Pal-3D and Pal-4D sectors primarily through Bayan South Fault. The next wells which may be affected by the fluid migration through Madanan and Makabug faults could include Sector I and 111 wells, where significant increases in the Cl-B molar ratios now approach that of the Masakrot fluid signature. This fluid invasion may help decrease the gas content in these production wells and could alleviate the persistent high % NCG problem at the Bacman I interface.

Significant decline in power output for the field in the last quarter of 1996 (12 MWe) is not related to Masakrot fluid inclusion, but can be mainly attributed to 1) large pressure drawdown in well Pal-8D (6.3 W e) , Pal-20D (3.2 MWe), and 2) cooler water inflows due to casing damage in well Pal-14D (2.1 **MWe)**. Evidences from gas chemistry and chemical cross plots suggest a possible gasdepleted colder fluid inflow in Pal-14D through the casing break which may not necessarily be the Masakrot fluid.

Downhole sampling should be undertaken at Pal-8D to fully assess its change in chemistry and decline in power output. For **Pal-14D**, downhole surveys and sampling should similarly be conducted to assess the casing damage and options for work-over.

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