Impacts of Mining in Watersheds:
Case of Open Pit Laterite Mining of Nickel and Iron Ores

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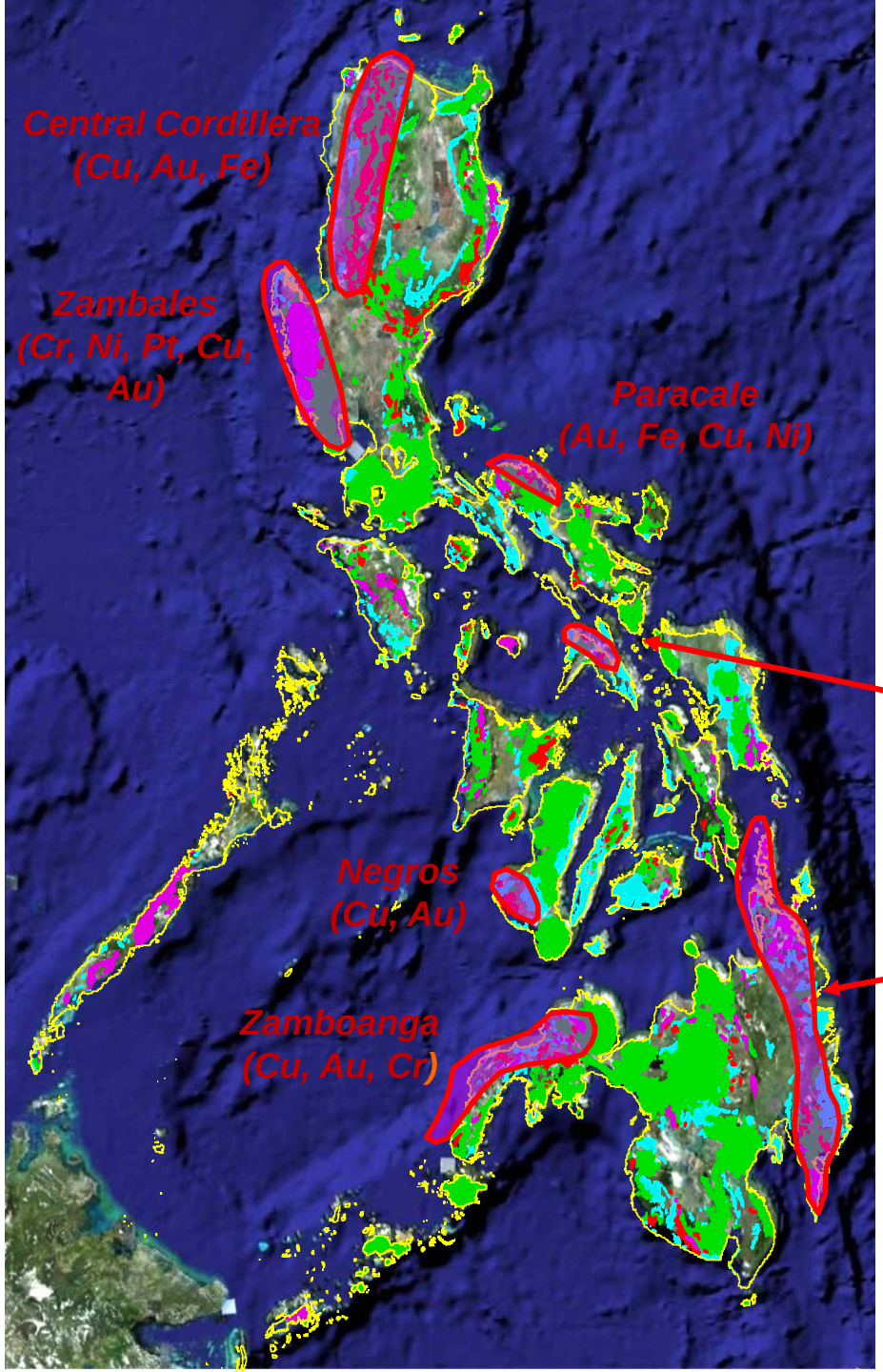
Outline of Talk

- Laterite Mining in the Philippines
- Mining Operations and Sample Companies
- Impacts of Open Pit Mining on Watersheds
- Policy Questions

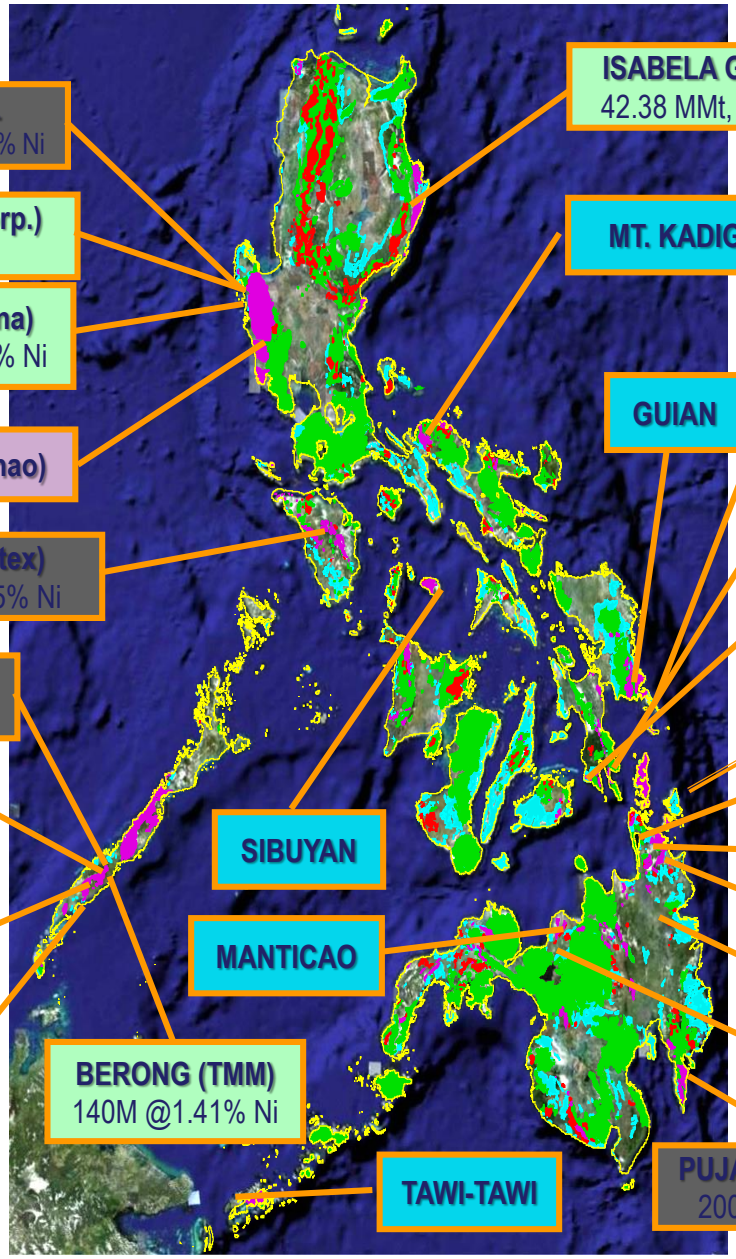


Mineral Districts of the Philippines

- Limestone
- Volcanic rocks
- Intrusive rocks
- Ultramafic rocks

[Slide from Dr. Sevillo David]

Philippine Nickel Deposits



GLOBAL
23 MMt, 1.75% Ni

STA. CRUZ (Benguet Corp.)
19.52 MMt, 1.36% Ni

ACOJE (Rusina)
30.2 MMt, 1.13% Ni

BOTOLAN (Nihao)

MINDORO (Intex)
87.53 MMt, 0.95% Ni

INFANTA (MacroAsia)
92.43 MMt, 1.01% Ni

TORONTO (Citinickel)
6.39 MMt, 1.80% Ni

PULOT (Citinickel)
8.21 MMt, 1.71% Ni

RIO TUBA
40.45 DMt 1.30% Ni

ISABELA Geograce
42.38 MMt, 1.16% Ni

MT. KADIG

GUIAN

SIBUYAN

MANTICAO

BERONG (TMM)
140M @1.41% Ni

TAWI-TAWI

MANICANI (NAC)
34.31 DMt, 1.11% Ni

CASIGURAN Century Peak
10.79 MMt, 1.11% Ni

CADGIANAO (NAC)
7.37DMt 1.64% Ni

NONOC
141 MMt, 1.10% Ni

HINATUAN (NAC)
3.0 DMt 1.50% Ni

CARRASCAL
21.0 MMt 1.10% Ni

TAGANITO (NAC)
75.6 Dmt 1.14% Ni

AGATA (MRL)
18.1 MMt, 1.13% Ni

BUKIDNON

PUJADA (Aiaticus)
200 MMt 1.3% Ni

[Slide from Dr. Sevillo David]

Typical Stratigraphic Column

Laterite Zone

0-3 M; 0.40- <0.80 % Ni
(depths) (contents)

Limonite Zone

3-8M; >1.80% Ni - >20% Fe

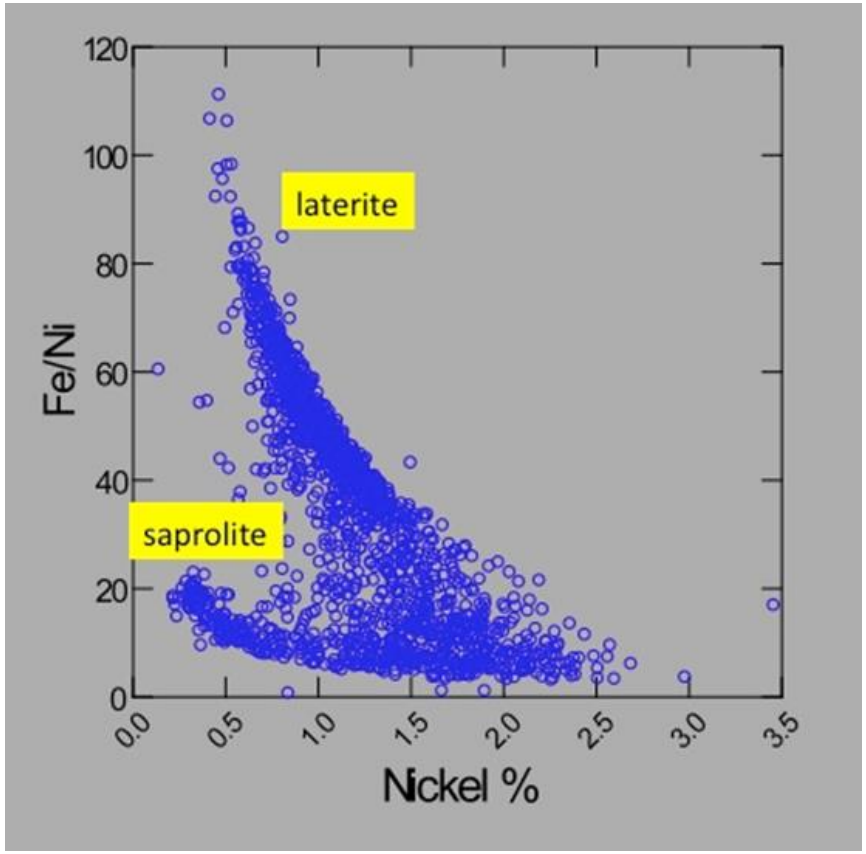
Saprolite Zone

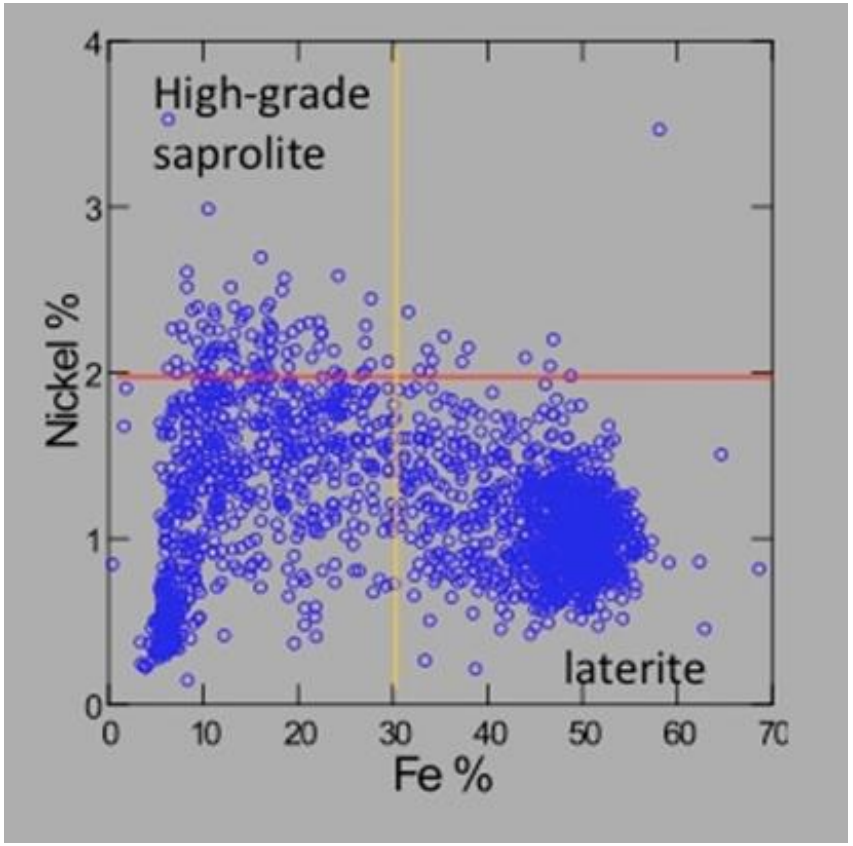
8-11M; >1.80 % Ni - < 20% Fe

Bed Rock

[Slide from Dr. Sevillo David]

Sample Nickel and Iron Contents in Laterite and Saprolite Layers





[Slide from Dr. Carlo Arcilla]

Mining Operations Flowchart

Stripping

Extraction

Progressive rehabilitation

Ship load

Barge load

Ore piling and drying

Refinery Plant

Ni & Co Products

[Slide from Dr. Carlo Arcilla]

Stripping

Stockpiling

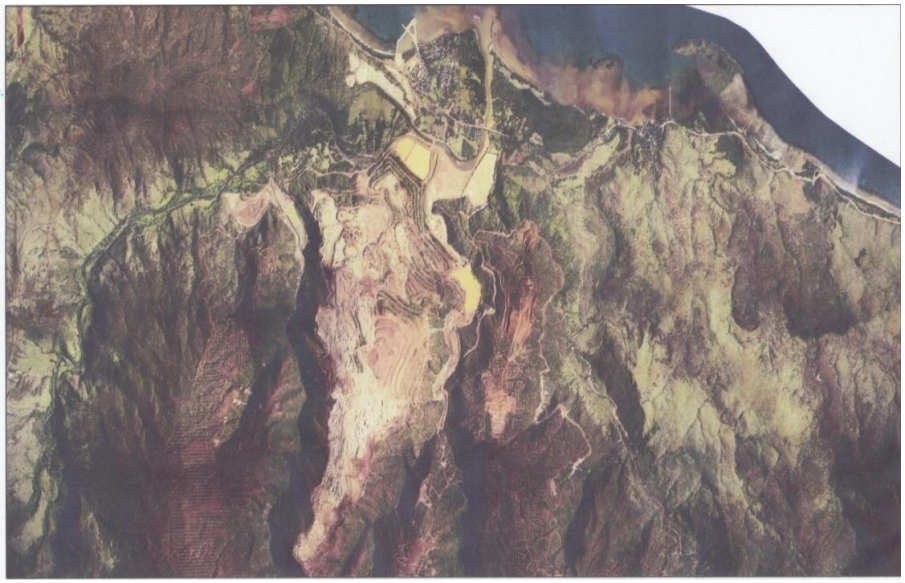
Grade Control

Moisture/Water Control

[Slide from Dr. Carlo Arcilla]

Taganito Mining Corporation

MPSA issued June 18, 2009; total area is 4,863 hectares in Barangays Taganito, Hayanggabon, Cagdianao, Urbiztondo and Claver of Surigao del Norte.



Ore Reserve as of December, 2009

	WMT	% Ni	% Fe
Saprolite (PAMCO)	11,880,381	2.02	10.12
Saprolite (CHINA)	9,526,595	1.69	10.54
Limonite (THPAL)	119,349,999	1.16	45.48

[Slide from Dr. Sevillo David]

Carrascal Nickel Corporation

ECC and MPSA Permit is for 4,567 hectares. Owned by CTP Construction and Mining Corporation Carrascal, Surigao del Sur

From 1998-999 report by Queensland Nickel Inc. Philippines covering 500 out of 4,567 hectares, identified laterite nickel ore with an average Nickel content of 0.9 to 1.1% amounting to Twenty-One Million Wet Metric Tons (21,000,000 WMT).

[Slide from Dr. Sevillo David]

Berong Nickel Project of Atlas Consolidated and Toledo Mining, Inc., Quezon, Palawan

Currently operating at about 500,000 to 600,000 metric tons with target of expanging to 1.5 million metric tons in 2016. Current grade are about 1.52% nickel and 29% iron.

[Slide from Dr. Sevillo David]

Impacts of Open Pit Strip Mining on Watershed Hydrologic, Hydraulic and Ecologic Processes (Especially during the Mining Period)

Key considerations to ensure ecological integrity of watershed and river systems based on understanding hydrologic, geomorphologic and ecologic interactions

1) the integrity of the water resource system, including its stability and resilience, are maintained if key structural characteristics, such as availability of refuges, continuity of river and floodplain habitat, river flow, sediments and morphology interact; and,

2) maintenance of natural hydrologic regimes with its associated geomorphologic and ecologic interactions is a major factor in maintaining and sustaining a naturally functional ecosystem.

- **The geomorphology and hydrology of a basin interact with each other since the morphology of the watershed and river system influences the shape and magnitude of the basin hydrograph; while the landform or morphology of the watershed and river system is shaped by the hydrologic or hydraulic flow regimes of the basin. In particular:**

  - **High flow regimes are generally responsible for removing or mobilizing sediments by erosion while the low flows promote deposition of sediments.**
  - **During high flows, rivers can flush fines and sand in the streambed gravel matrix.**
  - **The geomorphologic features of the river such as shape, slope and sediment size dictate the type of sediment load in the river as well as stability in terms of being straight, meandering or braided.**

- **Basin hydrology including watershed and river hydraulics interact with basin ecology since the biotic structures (i.e., species, composition and communities) and life cycles of the flora and fauna, highly depend on the seasonal variations of:**

  - **river flow especially its dilution effects on water quality,**
  - **channel velocity distribution,**
  - **frequency of bankfull-discharge condition or floodplain-river interaction,**
  - **floodplain recession rates,**
  - **water residence times, and**
  - **temporal and spatial frequencies of floodings.**

- **River geomorphology in terms of bathymetric features, sediment loads and water-sediment balance influences ecology in terms of biogeography as well as the birth and survivability of aquatic flora and fauna.**

- **For example, the spawning behaviour of certain fishes depend on the location in a river reach where they deposit and fertilize eggs in riffles or cobble bars and they rest and feed in pools (in a riffle-pool sequence) between spawning forays.**

- **Finally, ecology can affect geomorphology in terms of bioturbation such as burrowing organisms that cause resuspension of sediments in lakebeds or streambeds.**

Effects on Overland Flow Processes

The major operation in open pit mining is stripping of upper soil which includes removal of forest cover or vegetal cover. The effect to overland flow processes after stripping the soil are as follows:

- **Reduced interception capacity of forest and vegetal thus increasing direct runoff.**

- **Decreased infiltration rates since remaining soil is almost bedrock or hard pan resulting in increase direct surface runoff.**

- **Enhance soil erosion and transportation of sediments including metals attached to sediments from overland flow planes to the rivers and eventually into bays and estuaries.**

Effects on Watershed Landform and River Network

- **Stripping the upper 10 to 20 meters of soil definitely modifies the overland flow slopes and micro drainage landform by obliterating the natural rills, gullies and small channels of the watershed.**
- **Modification of this landform consequently changes the flow distribution and timing of overland flow production which could either result in lower flow velocities (due to decreasing slopes) or accelerate flow velocities (due to channel shortened channels).**
- **Consequently, sediment transport (erosion or deposition) could either be enhanced or reduced. For instance, in portions where the overland flow channels are shortened, there will be erosion upstream and deposition of sediments downstream. In the higher order streams (large channels) in particular, the effect is is even more pronounced such that deep encised channels can ensue upstream (thus prone to bank collapse) and massive deposition downstream (creating flooding problem due to swallowing of the river bed).**

Effects on Bays, Estuaries or Coastal Areas

- **The increased of sediment loads from the watersheds and rivers that eventually reaches the bays and estuaries will definitely have several and varying effects in the coastal areas (i.e., bays and estuaries).**
- **One is the change in littoral drift patterns (i.e., erosion and deposition cycles) in the coastal areas due to the increased sediment load distinct from the original, natural sediment regimes. Consequently, the coastal landform (especially mangrove zones) could change that can have adverse ecological impacts due modified sediment accumulation and flow distribution patterns in the coastal area.**
- **The sediment mineralogy and geochemistry that reaches coastal areas can likewise be drastically different that includes metals since the sediment loads are no longer from the usual top soil. The new sediment properties can be a source of pollution to the marine resources.**

Transport of metals bounded on laterite particulate matter transported by wind into watershed, rivers, bays and estuaries

- **The mining operations exposes and produces particulate matter (i.e., dust particles) light enough to be suspended in the air. This particulate metals bounded to the lateritic suspended particulate matter can be carried or transported by the winds into the watersheds, nearby rural and urban areas including bays and estuaries.**

- **During the dry season with seasonally strong winds, this laterite suspended particulates may be present at high concentrations and certainly poses air pollution problems. When rainy season comes, this suspended particulates can precipitate into bodies of water to become suspended or wash load in the river, lakes and estuaries.**

Effects of Wind and Flood Regimes on Geochemistry of Nickel

- **During the dry season, the concentrations of metal present in the water of bays and estuaries can be principally governed by the strong *amihan* or *habagat* winds.**

- **During the wet season, it is mainly due to floodwaters from watersheds into the bays and estuaries**

- **The driving forces behind the resuspension of particles can be attributed to the shallow depths present in the bay, the intense mixing and the resulting aggregation mechanisms. This resuspension phenomenon is responsible for the distribution of dissolved and particulate metals in the water column**

- **During periods of intense resuspension, it is observed that the adsorption of nickel (Ni) onto the sediment particles is enhanced and reversely, the concentration of dissolved nickel increased during the sedimentation (deposition) phase as a result of calm meteorological and hydrodynamic conditions.**

…. effects on bays

- **Redissolution of Ni seemed to be higher during the period of resuspension of the particles richer in carbonates.**

- **In terms of environmental impact, the amounts of lateritic particles that have accumulated over time can modify the geochemical equilibriums in the water column, particularly in shallow and sheltered bays.**

- **Reducing the concentration of suspended particulate matter injected into the bays and estuaries is essential to limit the effects of the bio-accumulation in exposed marine organisms.**



[Pictures from Dr. Carlo Arcilla]

Policy Questions and Discussions

- **Watersheds can be considered environmentally sensitive or ecologically of interest. In this case, the fear here is that mining these areas will significantly or drastically modify the watershed to adversely affect the watershed's ecosystem functions or services.**

- **The mining law allow mining up to 800 ha (10 blocks at 80 hectares per block) for individuals or 80,000 ha (20 blocks) for corporations. For exploration (with MPSA), it allows up to 1,600 ha (20 blocks) for individuals and 3,200 (40 blocks) for corporation.**

- **If these are mostly for purposes of open pit laterite mining, it will involve removing (by stripping) 10 to 30 meters of top soil to extract (access) the nickel and iron ore below this top soil.**

- **The big question is to what extent it will modify the watershed processes, and subsequently affect the delivery of ecosystem services.**

… policy questions

- **When the mining company had already extracted all the iron or nickel ore in the area, they are supposed to restore the watershed. Again, the question here is how can you realistically restore the watershed to bring back to its original ecosystem services when it is already stripped mine 20 to 30 meters of soil including the extraction of nickel and iron ore.**
- **The 1995 Mining Law defines what areas (lands) that mining is allowed. Areas not open to mining include: watersheds with old growth forest, near dams and reservoirs and other infrastructure projects, proclaimed forest reserves, national parks and especially declared environmentally sensitive or critical watershed.**
- **The areas open mining are clear except in the case of critical watersheds where the Forestry code says that a watershed can only be declared critical if it provides hydropower and water supply. Thus, this ignores other ecosystem services of a watershed such as biodiversity, flood control, livelihood from native flora and fauna, among others.**

… policy questions

- **With current environmental awareness and consciousness, the legalistic definition of environmentally sensitive or critical watershed may be obsolete and irrelevant.**

- **In general, the mining policy including the mining permit process should be seriously reviewed posed in terms of the following questions:**

  - **How can we sustain and ensure ecological integrity of the watersheds during and after mining period**
  - **What are the long-term implications to livelihood and community health and risks.**
  - **What are the real benefits (for whom, how much and in the long-term) and what are the costs (to whom, now and in the future). In particular, examine the economics of mining tradeoff of benefits to companies and government versus costs to environmental degradation and restoration.**

Last slide!