



Original Research Article

The use of *Pleurotus sapidus* immobilized on Dowex®1×4 resin as a novel biosorbent for preconcentration of uranium (VI)

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ABSTRACT

Keywords

Pleurotus sapidus,
Dowex®1×4,
Uranium
(VI), Spectro-
photometer

The main goal of this work was focused on using the *Pleurotus sapidus* immobilized on Dowex®1×4 as a new biosorbent for removal of U(VI) ions. The procedure is based on using Dowex®1×4 resin as a support material with dried, dead fungal biomass for column preconcentration of U(VI) ions. Various parameters such as pH, amount of adsorbent, eluent type and volume, flow rate of sample solution, volume of sample solution and matrix interference effect on the retention of the metal ions have been studied. Maximum biosorption of U(VI) ions took place at pH 6.5. These ions can be desorbed with 1M HCl (recovery 98%). 0.2 g adsorbent amount and 1 mL/min flow rate was found to be optimum of all preconcentration experiments. The sorption capacity after 10 cycles of sorption and desorption does not vary more than 2.0%. Using SEM and IR techniques revealed that *P. sapidus* immobilized on Dowex®1×4 resin can be considered as a promising choice as a new biosorbent for U(VI) ions removal.

Introduction

With the development of nuclear power plant, uranium removal and recovery from its ores and environmental samples have been explored in order to meet the energy demand for the near future. Uranium mining and mineral processing for nuclear power have also resulted in the generation of significant amounts of radioactive wastes with tremendous environmental impact (Kazy *et al.*, 2009). Biosorption is the property of biomaterials to bind and concentrate heavy metals / radionuclides from aqueous solutions. It has been regarded as an innovative technology to remove contaminants from industrial effluents

(Wang, 2002). Biosorption has become a method of choice as compared to traditional methods of waste waters treatment such as precipitation, adsorption, coagulation, etc. as it is economically and environmentally more viable (Khambhaty *et al.*, 2009). The use of dead biomass is more advantageous than the use of live biomass because there are no toxicity concerns, no requirements of growth media or nutrients and there are easy techniques to desorb contaminants from the biomass and reuse them (Mathialagan *et al.*, 2009). Fungi cell walls contain large quantity of polysaccharides and proteins, which offer many functional groups (such as

carboxyl, hydroxyl, sulphate, phosphate and amino groups) for binding metal ions (Zhou *et al.*, 2004).

For application of biosorption the use of freely suspended biomass have several disadvantages, like post-separation of suspended biomass from the treated effluent, compaction, clogging, maintenance of biosorbent stability, washout from the system and regeneration of used biosorbents (Liu *et al.*, 2003). In contrast to this, application of immobilized biomass has many advantages including increased mechanical strength, density, resistance to chemical environment, easy separation of cells and effluents (solid-liquid), minimal clogging in continuous-flow systems, high biomass loading/performance and repeated use in many subsequent adsorption/desorption cycles in the usual unit processes characteristics of chemical engineering (Arica *et al.*, 2001). The potential of immobilized microorganisms to remove metals from the aquatic environment has been widely appreciated (Bajpai *et al.*, 2004 & Aloysius *et al.*, 1999).

Materials that have been successfully used for cell entrapment include agar, agarose, alginate, k-carrageenan, polyacrylamide, polyurethane, cellulose, collagen, chitin, chitosan, polysulfone and epoxy resins (Akhtar *et al.*, 2009). Most of these polymers are also known to bind metal ions strongly (Jang, 1993). The entrapment of microbial cells in these polymers supports could also enhance the adsorptive capacity of the biosorbent system for the heavy metal ions. Commercial availability of pure resin, uniform pore distribution, high surface area, durability and chemically homogenous structure are the main advantageous of Dowex®1×4 over other support materials. (Kocaoba and Arisoy, 2011) studied the use of *Pleurotus ostreatus* immobilized on

Amberlite XAD-4 as a new biosorbent in trace metal determination. The main concern of this work was the use of the column packed with *P. sapidus* immobilized on Dowex®1×4 resin for the preconcentration of U(VI) ions in aqueous solutions. The metal loading capacity of modified biomass was determined as a function of “pH, amount of adsorbent, flow rate of sample solution, type and volume of elution solution, volume of sample solution, column reusability and interfering ions”. The proposed method was applied to the preconcentration of U(VI) ions in leaching liquor of granitic rock ore sample.

Materials and Methods

Ore minerals and leaching procedure

In the present work, a proper sample of mineralized granitic rock was used. The study area is situated in the Halaib district, South Eastern Desert, along the Red Sea coast. The monzogranites are characterized by medium to coarse-grain crystals, red colour, highly weathered surfaces and presence of numerous joints and fractures. They mostly include uraniferous alteration zones and are injected by quartz, jasper and pegmatitic veins, these granites occur in an isolated hill.

This zone is characterized by several alteration process such as ferrugination, silicification, grizenization and kaolinitization. Mineralogical studies were Revealed the presence of secondary uranium minerals (uranophane and autonite). This area is located about 25km west of Abu Ramad City on the coastal highway. It is located between Lat. 22° 13` - 22° 20` N and Long. 36° 08` - 36° 17` E (Fig. 1). The general geology and mineral deposits of the Halaib district were studied by several authors (Abdel Meguid *et al.*, 2003).

The chemical leaching of granitic rock sample was achieved according to (El Hazek *et al.*, 2008). The optimum leaching conditions were 800 g/L sulfuric acid with a Solid/Liquid ratio of 1/2 at 100°C for 4 h.

Microorganism and growth conditions

White-rot basidiomycete *P. sapidus* was used in the experiments. The stock cultures of organism were maintained on the malt agar slants. The culture medium is a modification given by Eaton (1985). The culture medium contained (g/L) “10 glucose; 0.12 NH₄Cl; 2.6 K₂HPO₄; 0.5 MgSO₄; 0.1 CaCl₂; 0.001 thiamine”. The pH value of medium was 4.5. The culture was incubated at 30 °C, 150 rpm for 15 days. After 15 days of growth, the harvested cells were washed twice with deionized distilled water and in order to improve the metal binding properties, intact cells were boiled in 0.5 N NaOH solution for 15 min and then washed with generous amounts of deionized distilled water till the pH of the wash solution was in the near neutral range. Then, it was dried at 60 °C for 24 h before use.

Reagents

Analytical reagent grade HCl and NaOH, chemicals from Merck (Germany), UO₂(NO₃)₂.6H₂O atomic absorption spectrometry standard solutions (1000 mg/L) (Science lab.com) were used. Working solutions of the metal ions were prepared by a suitable dilution of a stock solution with doubly distilled water. Dowex®1×4 resin was used as a support material for the immobilization of *P. sapidus*. Dowex®1×4 (surface area 725 m²/g, cross-linkage 4% and bead size 50-100 mesh) was supplied by Ubichem limited, UK. Dowex®1×4 resin obtained from the supplier contained organic and inorganic impurities. To remove the

contaminants, it was treated with 4 M HCl. The resin was firstly rinsed with distilled water until its pH was neutral, secondly with an ethanol-water (1:1) solution and finally with distilled water again. Then, it was stored in a polyethylene bottle.

Immobilization of the microorganism on Dowex®1×4 resin

The immobilization of *P. sapidus* was performed according to the procedure recommended by Mahan and Holcombe (1992). 200 mg of dry *P. sapidus* was mixed with 2 g of Dowex®1×4 resin. The mixture was wetted with 2 mL of doubly distilled deionized water and thoroughly mixed. After mixing, the paste was heated in an oven at 80 °C for 24 h to dry the mixture. The wetting and drying step was repeated to maximize the contact between fungi and resin, thereby improving the immobilization efficiency. Then, the product obtained was ground to get original size (20–40 mesh) and used as an adsorbent.

Preparation of the column

P. sapidus immobilized on Dowex®1×4 resin (0.2 -0.3 g) was packed in a glass column. Before use, a 1 mol/ L HCl solution and doubly distilled water were passed through the column in order to condition and clean it. Then, the column was conditioned to studied pH by passing an aqueous solution of HCl or NaOH having the same pH as that of sample solution through the column, prior to passage of the sample solution.

General procedure for enrichment the sorption studies

An off-line column procedure was applied for preconcentration. An aliquot of the sample solution containing 100 ppm U(VI) ions in 100 mL was taken and the pH was

adjusted to the optimum value, determined experimentally with HCl or NaOH. The samples at the chosen pH were passed through the column at appropriate flow rates determined experimentally. After passing this solution completely, the retained metal ions were then eluted from the solid phase with a suitable eluent. The concentration of the metal ions in the eluate was determined by spectrophotometer apparatus (Metertech Ino model Sp-5001, UV-Visible spectrophotometer). *P. sapidus* immobilized resin was used repeatedly after washing with 1 M HCl solution and then doubly distilled water.

SEM observation

The texture, pore structure and loaded biomass of *P. sapidus* immobilized on Dowex®1×4 resin were observed under high resolution Environmental Scanning Electron Microscope (ESEM), Philips XL30 vacuum at 30 KV.

Infrared Analysis

Infrared spectrophotometer was used to determine the functional groups presented on the surface of *P. sapidus* immobilized on Dowex®1×4 resin before and after loading with U(VI) ions. The apparatus used (Model JASCO 4100 FTIR spectrophotometer, Japan) which presented in the Micro Analytical Center, Cairo University, Egypt. The samples were prepared as KBr discs.

Result and Discussion

Although there are many studies on accumulation of heavy metals in living and non-living biomass, where a little information has been published on the preconcentration of trace metals by using microorganisms as biosorbent materials. Column procedures which are time

consuming and allow easier regeneration of the biosorbent have been already used to immobilize fungi, yeast and algae (Godlewska-Zylkiewicz, 2006).

In this paper, the effects of experimental parameters, such as “pH, amount of adsorbent, flow rate of sample solution, eluent type and volume and interfering ions” on the recovery of the metal ions were investigated.

Chemical analysis of leach liquor of granitic rock ore

The chemical composition of granitic rock ore was shown in Table1.

Effect of pH

Biosorption of the metal ions in the mini column is attributed to ionic attraction between the metal ions and functional groups of the biomass (Rao *et al.*, 2006). In order to find the effect of pH on the degree of metal biosorption, an amount about of 250 mg Dowex®1×4 resin loaded with *P. sapidus* was packed in glass column and 50mL metal solution containing 100 ppm U(VI) ions was passed at optimum flow rate about 2mL/ min at various pH values (pH: 2–9). The metal ions were then eluted by 1M HCl. Therefore, the pH of the metal solution is an important parameter to study in this system (Gama *et al.*, 2006) because the influences of pH of the aqueous solution on the retentions of the metal ions on *B. subtilis* immobilized XAD-4 resin is strongly dependent on hydronium (or hydroxide) ions concentration in the media.

It was found that the maximum degree of sorption (88.99 %) for U(VI) ions at pH value 6.0. From the results shown in Fig.2, it could be concluded that the cell surface becomes positively charged at low pH

values which decrease the attraction between metal ions and the functional groups on the cell wall, whereas the cell surface becomes negatively charged at high pH values, increasing the attraction until a maximum is reached at around pH 6.0. For pH values higher than the optimum values, the retention decreases again due to the competition between the hydroxylated complexes of the metal and active sites of the cell. Similar results were obtained with *Agrobacterium tumefaciens* immobilized on Amberlite XAD-4 (Baytak and Türker, 2005).

Effect of amount of adsorbent

Effect of adsorbent amount on sorption studies of U(VI) ions by *P. sapidus* immobilized on Dowex®1×4 resin is presented in Fig. 3. It was found that above 0.1 g of adsorbent the recovery of uranium gradually increased, but about 0.2 g of adsorbent reached plateau. Therefore, 0.2 g adsorbent was found to be optimum for all preconcentration experiments.

Effect of flow rate of sample solution

The flow rate of the sample solution affects the mass transfer from the solution to the binding sites on the cell wall of microorganism. For that reason, the retention of element on an adsorbent depends upon the flow rate of the metal solution. The degree of metal ion sorption on the Dowex®1×4 resin loaded with *P. sapidus* (0.2g) was studied at various flow rates of the metal ion solution. Twenty five milliliter containing its 100 ppm U(VI) ions was adjusted to the optimum pH value. The solution was passed through the column with the flow rates adjusted in a range of 1–6 mL/ min. The optimum flow rate for the metal ion was 1mL/min (Fig. 4). Flow rates slower than 1mL/min were not studied to avoid long analysis times. However, at a

flow rate greater than 3mL/min, there was a decrease in the percentage of sorption, as the metal ion could not equilibrate properly with the resin bed. The flow rate of 1mL/min was found most effective for stripping the metal ion from the matrix. Similar results were obtained with *Pleurotus ostreatus* immobilized on Amberlite XAD-4 (Kocaoba and Arisoy, 2011).

Effect of the type and volume of elution solutions

The other important factor, that affects the preconcentration technique, is the type and concentration of the eluent used for the release of metal ions from the bacterial surface. The concentration of the acid used as an eluent must be the lowest possible level in order to prevent degradation of the biomass (Bag *et al.*, 2000). Optimization of the elution conditions was performed in order to obtain the maximum recovery with the minimal concentration and volume of the elution solution. The effect of different volumes of hydrochloric, nitric and sulphuric acid in water was tested to remove the bound metal ions from the fungal biomass loaded onto the column. The elution studies were performed with 1 mol /L HCl, HNO₃ and H₂SO₄ solutions. The eluate volume was 5, 10 and 15 mL. As can be seen from Table 2 it was found that 15 mL of 1 mol / L HCl solution was found to be satisfactory for recovery (98 %) of U(VI) ions. A similar result was obtained by (Akhtar *et al.*, 2009) where they used 0.1 N HCl as eluting agent for desorption of uranium from Ca- alginate immobilized *Trichoderma harzianum*.

Effect of the volume of sample solutions

The effect of changes in the volume of sample solution passed through the column on the recovery of U (VI) ions was investigated in order to determine an

applicable sample volume or a minimum analyte concentration. For this purpose, 5, 10, 15, 20 and 25 mL volume solution containing 20, 10, 5, 2.5 and 1.25 µg/L of U (VI) ions were passed through the column under the optimum conditions. It was found that all metal ions could be recovered quantitatively ($\geq 95\%$) up to 5 mL of the sample solution (Fig. 5). At the higher volumes, the recoveries for analytes decreased. In this study, the elution volume was 5 mL, therefore the preconcentration factors were 5 for the analytes. These results showed that U(VI) ions could be uptake in low concentrations by the proposed method.

Effect of column reusability

In order to determine the stability and potential recyclability of the column, the change in the recoveries of U(VI) ions through several adsorption-desorption cycles were studied. Uranium metal ions were adsorbed and desorbed on about 250 mg of *P. sapidus* immobilized on Dowex®1×4 resin several times using (25 mL) having a concentration of 40 µg/L of U (VI) ions under the optimum experimental conditions. It was found that the sorption capacity after 10 cycles of sorption and desorption does not vary more than 2.0% (Fig.6). The columns seem to be relatively stable up to 10 cycles. Therefore, repeated use of the resin is possible.

Effect of interfering ions

In order to investigate the effect of the interfering ions, especially Al(III), Na (I), K(I) and Fe(III) were added to a synthetic sample solution containing U(VI) ions. The recovery of U(VI) ions was also examined when they existed together in the same medium. The concentrations of interfering ions were 1, 10, 50 and 100 µg/mL and the concentrations of these ions were adjusted

over the range of 1- 40 µg/mL. Other ions present in the solution have generally a negative impact on the metal retention because of the competition between analyte and diverse ions. The results were given in Table 3. As can be seen in the table, Al^{3+} , Na^+ , K^+ and Fe^{3+} did not interfere in the uptake of U(VI) ions up to 50 µg/mL.

Characterization of the biosorbent system by scanning electron microscope (SEM) and infrared analysis spectral analysis (IR)

SEM observation

Plate.1A. appeared the hydrochloric acid treated Dowex®1×4 resin. Thus generate clean surface morphology where resin beads are spherical approximately 4 mm in diameter. Plate.1B. appeared the global intact fiber like structure of sodium hydroxide treated *P. sapidus* biomass. Alkali treatment can cause hydrolysis of protein and also deacetylation of chitin. All those changes control adsorption capacity of modified mycelia increased. The fungal mycelia have rough and porous surface. This surface property should be considered as a factor providing an increase in the total surface area. In addition, the micropores on the fungal biomass could reduce the diffusional resistance and facilities mass transfer because of their high internal surface area (Kamari *et al.*, 2009). The SEM micrograph of unloaded fungus immobilized on resin was completely different from loaded one. Plate. 1C. showed unloaded *P. sapidus* immobilized on Dowex®1×4 resin before adsorption of uranium ions. All microstructures porosities of immobilized *P. sapidus* seemed to be not filled with U(VI) ions where no bright color appear. Plate. 1D. appeared *P. sapidus* immobilized on Dowex®1×4 resin after adsorption of uranium ions. All

microstructures porosities of immobilized *P. sapidus* seemed to be filled with U(VI) ions. Resin immobilization has also been reported to enhance the metal ions uptake potential of a white rot fungi (*Pleurotus ostreatus*) in batch system (Kocaoba and Arisoy, 2011). The biosorptive efficiency of biomass enhanced due to the fact that resin itself is also a good sorbent. Therefore resin was selected as a suitable immobilization matrix for further scale up studies.

IR spectral analysis

FTIR spectra are useful tool to identify functional groups in a molecule, as each specific chemical bond often has a unique energy absorption band and can obtain structural and bond information on a complex to study the strength and fraction of hydrogen bonding and miscibility (Li and Bai, 2005). Fig.7. shows typical FTIR spectra for *P. sapidus* immobilized on Dowex®1×4 resin before and after the biosorption of U(VI) ions. FTIR spectra of the biosorbents are recorded in the range of 400-4000 cm^{-1} to obtain the information regarding stretching and bending vibrations of the functional groups which are involved in the biosorption of U(VI) ions also, as summarized in Table. 4.

In general, the biosorption band of 3200-3600 cm^{-1} representing –OH stretching of carboxylic groups and also representing stretching of –NH groups. The peak at 2850-2970 cm^{-1} belongs to CH stretching vibration. Peak at 2100-2149 cm^{-1} represented $\text{C} \equiv \text{C}$ group of terminal alkynes. The spectra displayed the peaks of 1630 and 1639 cm^{-1} represented the C=O group of carboxylic acid (Akhtar *et al.*, 2009). There is a slight shift in the overall spectra except, the shift in the intensity of peak at 1380 cm^{-1} strengthened after uranium adsorption, confirming the role of

C (=O)–O– stretching vibration in uranium biosorption (Pan *et al.*, 2007). The peak appeared at 978 cm^{-1} after biosorption of uranium and also the peak at 1076 cm^{-1} disappeared and 1303 cm^{-1} . According to Merroun *et al.* (2003), peak at 978 cm^{-1} belongs to the stretching vibrations of uranyl ions. The disappearance of peak at 1076 cm^{-1} in spectra after uranium biosorption indicated the role of phosphate group in uranium biosorption. Involvement of phosphate group in intracellular metal uptake was also reported in the form of polyphosphate granules localized in or close to the vacuoles.

Application for removal of uranium from granitic rock ore of Gabal El Sela Area, South Eastern Desert of Egypt

Uranium minerals in the study area are mainly of the secondary type which reflects the alteration processes under surface oxidation conditions. The ENE-WSW shear zone in the northern part of the study area is characterized by presence of kaolinite pockets results from intensive alteration to the diabase dyke. Uranophane, associated with autonite and uranothorite occurs either as a thin flakes with yellow colors adsorbed on the cleavage planes and in between the sheeted flakes of kaolinite, silica veins or as micro fracture filling, cavity filling and on parting places between two minerals (considered as weak planes for movement of solution bearing mineralization) in highly fractured, silicified and ferruginated granite close to the shear zone.

Uranophane is the alteration product of uraninite, and the chief constituent of the outer silicate zone of the gummite type of uraninite alteration. Uranophane is usually associated with its dimorph, namely, beta-uranophane as appeared in Fig. 8 (A).

Autunite, is a secondary uranium mineral found chiefly in the zone of oxidation and weathering derived from the alteration of uraninite or other uranium – bearing veins. Autunite is a radioactive mineral characterized by yellow-green tetragonal plates and strong fluorescence in ultraviolet light as shown in Fig. 8 (B).

At the optimum leaching 100g of tested sample was leached using conditions 800 g/L sulfuric acid with a Solid/Liquid ratio of 1/2 at 100 °C for 4 h, It was found that, the percent of uranium leaching approach about 89.60 % . After leaching, the pregnant leach liquor contain (%) $\text{Fe}_2\text{O}_3 = 4.10$, $\text{P}_2\text{O}_5 = 0.3$, $\text{CaO} = 0.4$, $\text{UO}_2^{2+} = 0.2600$, $\text{RE}_2\text{O}_3 = 0.6$ and $\text{ThO}_2 = 0.1$. This liquor treated by adding gradually drop by drop of sodium hydroxide (20%) to remove iron at pH=3-3.5 which caused interference with uranium removal. The pretreated pregnant leaching liquor was passed through the recommended column for preconcentration of uranium at optimum conditions pH=6.5, amount of biosorbent=0.2g, at flow rate=1 mL/min and 1 M HCl as desorbent agent. After loading the prepared column with the pretreated pregnant leach liquor, it was found that, the biosorption percent of uranium was 73.50%. Furthermore, 88 % of biosorbed U(VI) ions were desorbed by 1 M HCl. Finally, 170 mg was obtained as a yellow cake (sodium diuranate). Less removal of U(VI) ions occurred in pregnant leach liquor solution as compared to synthetic U(VI) ions solution might be attributed to the presence of interference of other elements in the pregnant solution that compete with U(VI) ions for binding sites on the biosorbent. Similar observation was also reported by (Katsumata *et al.*, 2003).

Solid phase extraction offers several advantages. These include (i) flexibility, (ii) higher enrichment factors, absence of emulsion, low cost because of lower consumption of reagents, more importantly environment friendly, (iii) the preparation of the extractor system is simple and fast, (iv) high tolerance to interferences from the matrix ions allows the application of the proposed procedure for uranium removal in a large range of samples, (v) the reusability of the column several times (Dogru *et al.*, 2007).

The results presented in this paper demonstrate the usability of a new biosorbent, *P. sapidus*, for the preconcentration of uranium. The biomass, with higher metal sorption capacity and mechanical strength after immobilized on Dowex®1×4 resin, may find potential application for uranium ions removal. The analytes could be preconcentrated using the recommended column technique. Only 0.2 g of adsorbent is needed. The optimum pH was chosen as pH 6.5 for U(VI) ions. The optimum flow rate was found to be 1 mL/min. It was found that 15 mL of 1 M HCl satisfied for desorption about 98% of U(VI) ions. Uranium removals from pregnant leach liquor of granitic rock ore by *P. sapidus* immobilized on Dowex®1×4 resin was found 73.50% (170mg). The procedure shows improved retention of analytes, better repeatability, and multiple applications possibilities of the column (about 10 runs). The matrix effects were reasonably tolerable. In conclusion, the proposed method is excellent as regards simplicity, sensitivity, selectivity, precision, accuracy and column stability.

Table.1 The chemical composition of granitic rock ore

Sample	Elements (%)										
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	Na ₂ O	K ₂ O	CaO	MgO	P ₂ O ₅	UO ₂ ²⁺	ThO ₂	RE ₂ O ₃
Granitic rock ore	73.10	14.50	4.39	4.28	0.85	0.53	0.77	0.43	0.2962	0.113	0.75

Table.2 Effect of the type and volume of elution solutions on the recovery of U(VI) ions

Type of elution solution	Volume (mL)	Concentration (mol/L)	Recovery (%)
HCl	5	1	48
	10	1	68
	15	1	98
HNO ₃	5	1	30
	10	1	52
	15	1	86
H ₂ SO ₄	5	1	17
	10	1	40
	15	1	82

Table.3 Effect of interfering ions on the recovery of U(VI) ions

Interfering ion	Concentration (µg/ml)	Recovery(%)
		U(VI)
Al ³⁺	1	97
	10	95
	50	88
	100	81
Na ⁺	1	97
	10	95
	50	92
	100	90
K ⁺	1	97
	10	95
	50	93
	100	91
Fe ³⁺	1	97
	10	95
	50	90
	100	85

Table.4 Infrared spectra of *P. sapidus* immobilized on Dowex®1×4 resin before (A) and after (B) biosorption of U(VI) ions

	Band	Type of compound	Frequency (cm⁻¹)	Reference frequency range (cm⁻¹)
Before Biosorption	O-H	Hydrogen bonded alcohols	3428	3200-3600
	C-H	Alkynes	2925	2850-2970
	C ≡ C	Terminal alkynes	2119	2100-2140
	C=O	Carboxylic acid	1639	1550-1820
	C-H	Alkyl methyl	1380	1340-1470
	C-N	Amines-amides	1303	1180-1360
	C-O	Ethers- aromatic	1220	1220-1260
	C-O	Esters	1147	1100-1300
	P-H	Phosphine (P-H bending)	1076	950-1250
	C-H	Aromatic(meta-disub.benzene)	889	860-900
	C-H	Aromatic (monosubstituted benzene)	710	700-750
	C-X	Chloroalkanes	571	540-760
After biosorption	O-H	Hydrogen bonded alcohols	3428	3200-3600
	C-H	Alkynes	2924	2850-2970
	C ≡ C	Terminal alkynes	2100	2100-2140
	C=O	Carboxylic acid	1630	1550-1820
	C-H	Alkyl methyl	1381	1340-1470
	C-O	Ethers-aromatic	1220	1220-1269
	C-O	Esters	1121	1100-1300
	P-H	Phosphine(P-H bending)	978	950-1250
	C-H	Aromatic(meta-disub.benzene)	887	860-900
	C-H	Aromatic (monosubstituted benzene)	709	700-750
	C-X	Chloroalkanes	574	540-760

Fig.1 Location and geological maps of study area (modified after Abdel Meguid et al., 2003)

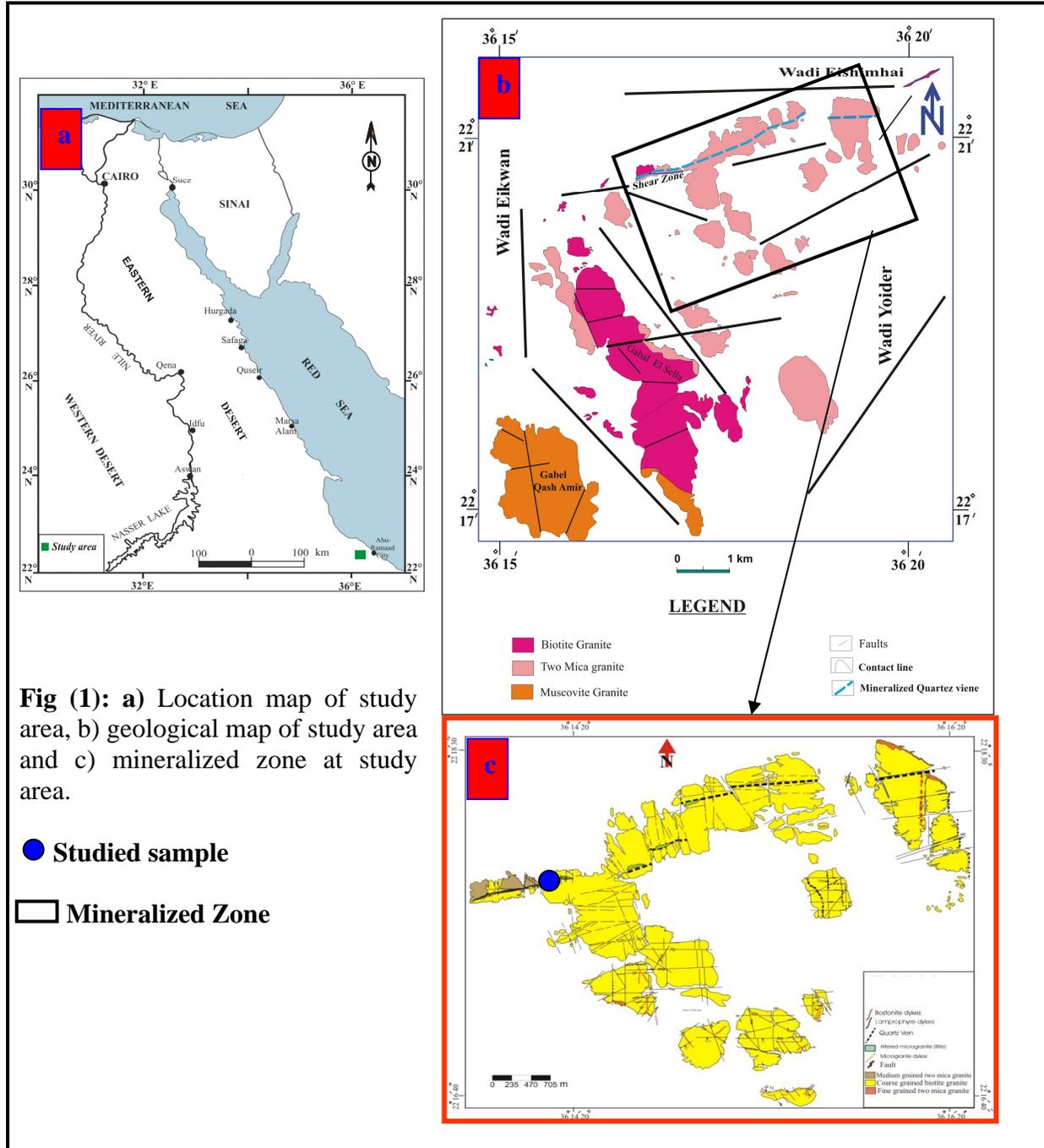


Fig.2 Effect of pH on the recovery of uranium by *P. sapidus* immobilized on Dowex®1×4 resin

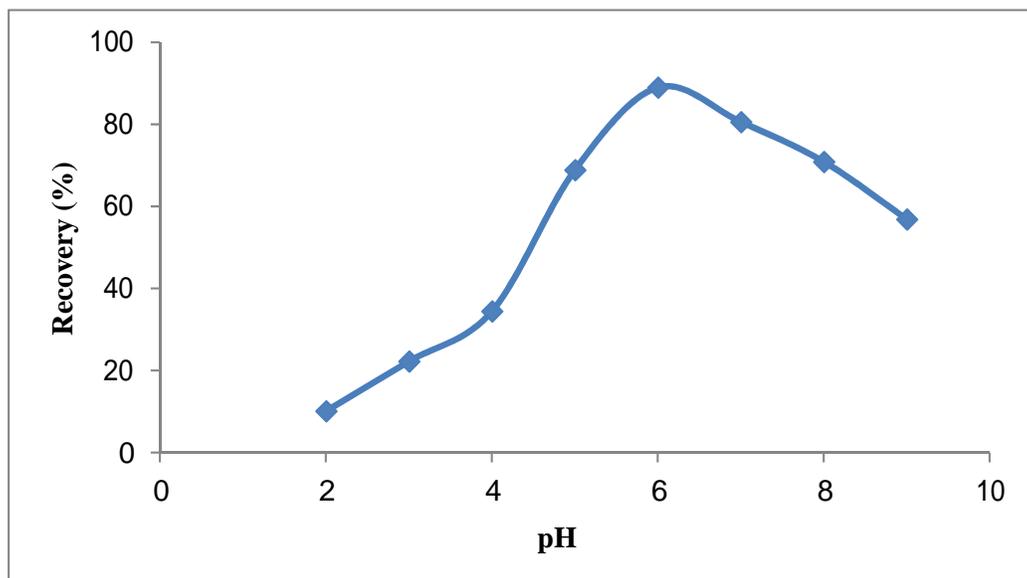


Fig.3 Effect of adsorbent amount (mg) on the recovery of uranium by *P. sapidus* immobilized on Dowex®1×4 resin

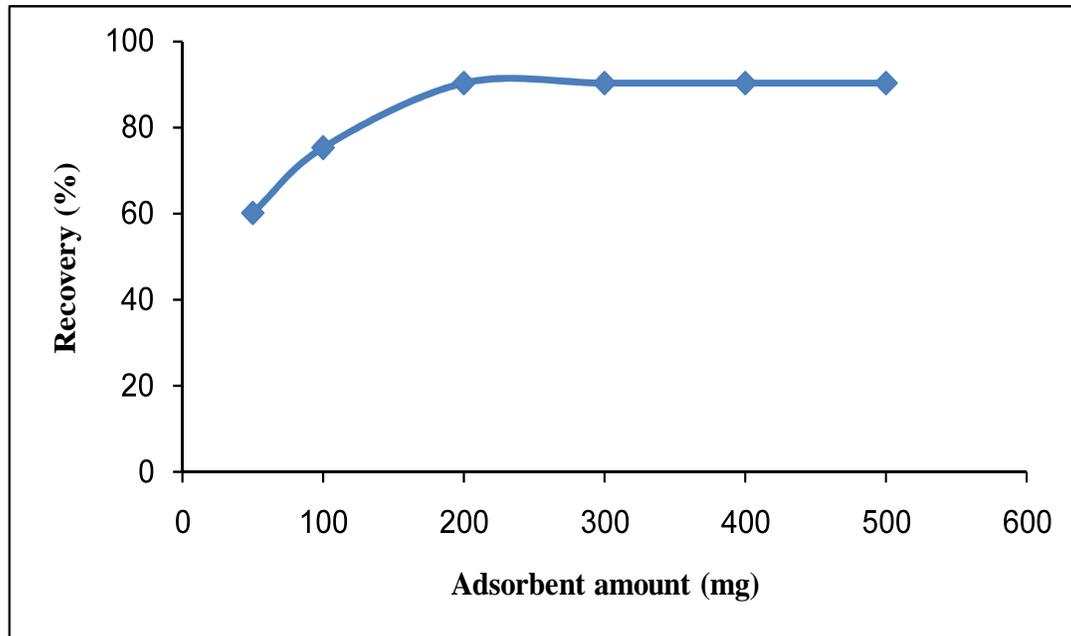


Fig.4 Effect of flow rate on the recovery of uranium by *P. sapidus* immobilized on Dowex®1×4 resin

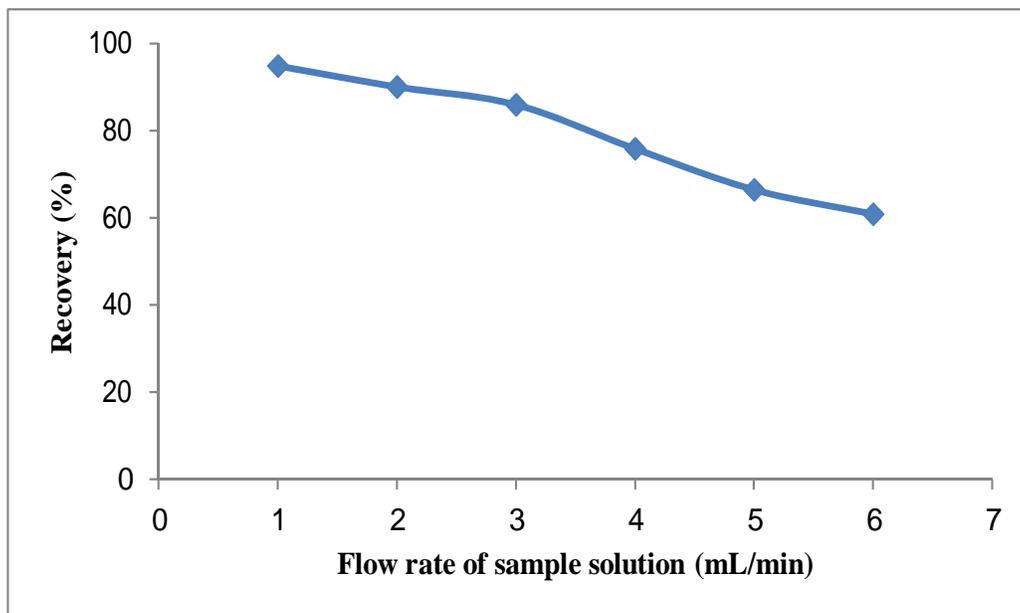


Fig.5 Effect of volume of sample solutions (mL) on the recovery of uranium by *P. sapidus* immobilized on Dowex®1×4 resin

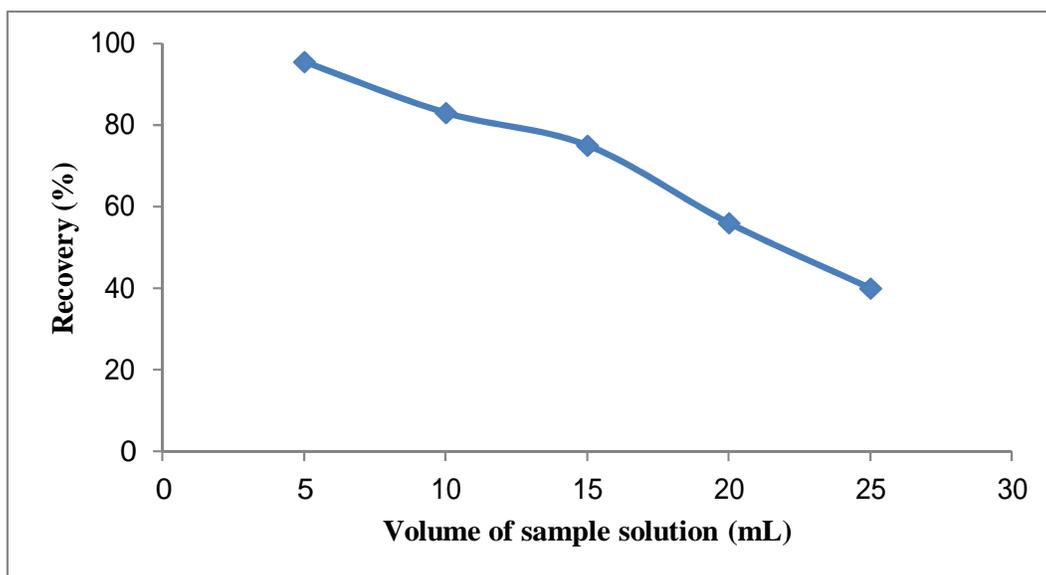


Fig.6 Effect of column reuse on the recovery of uranium by *P. sapidus* immobilized on Dowex®1×4 resin

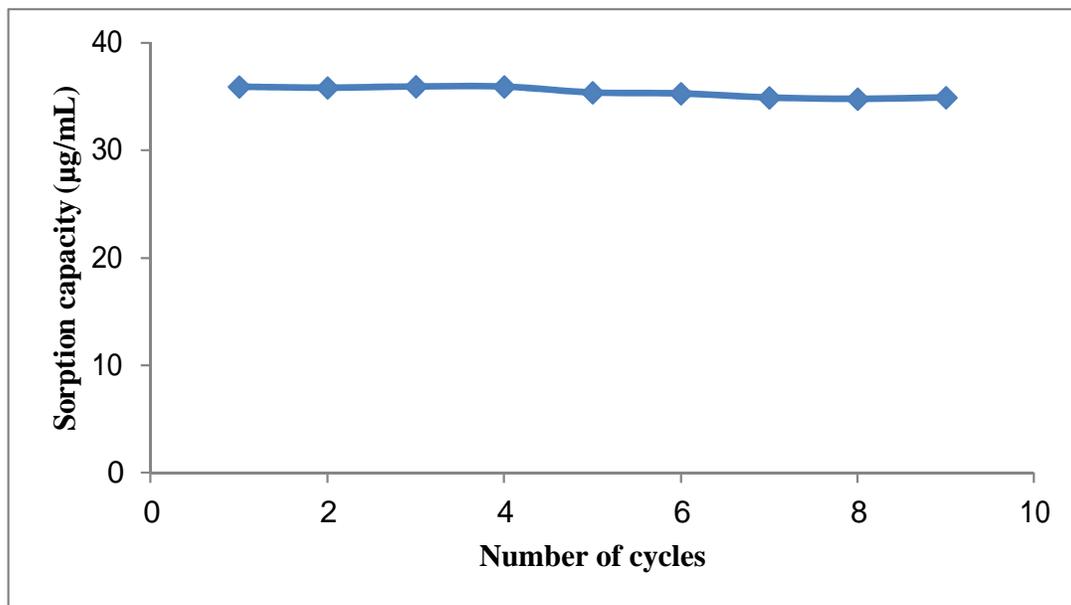
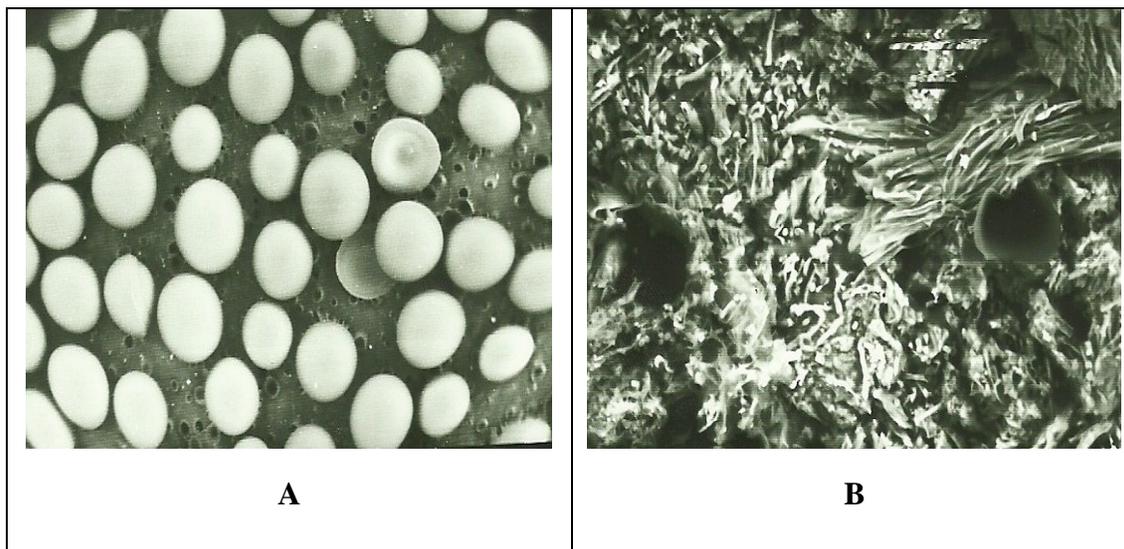


Plate.1 SEM photographs at 500 X magnifications were shown in the plate: parts A) treated Dowex®1×4 resin, B) treated *P. sapidus* biomass by NaOH, C) loaded on *P. sapidus* biomass immobilized on Dowex®1×4 resin (and D) U(VI) ions loaded on *P. sapidus* biomass immobilized on Dowex®1×4 resin



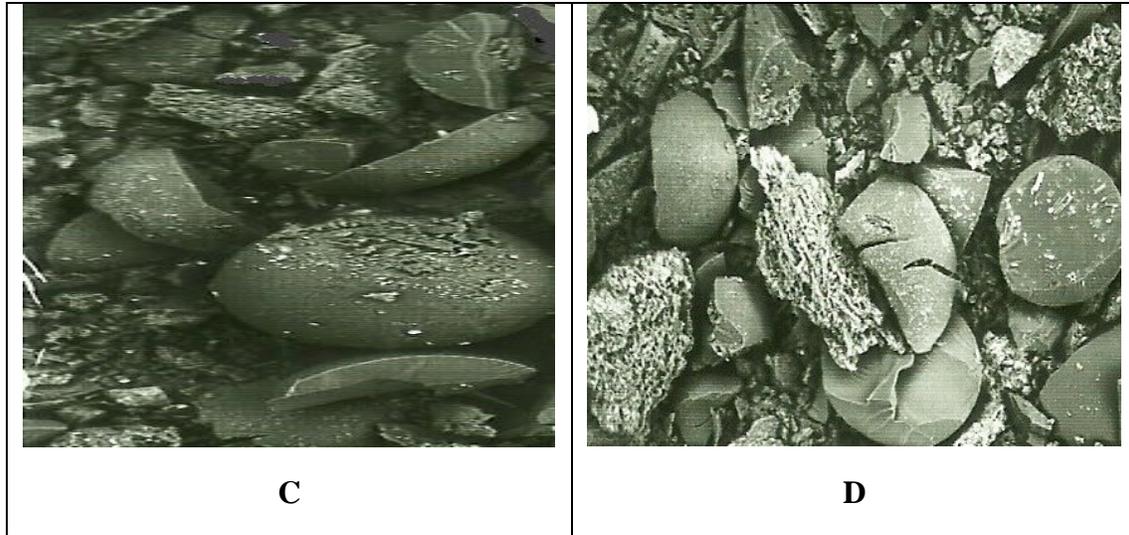
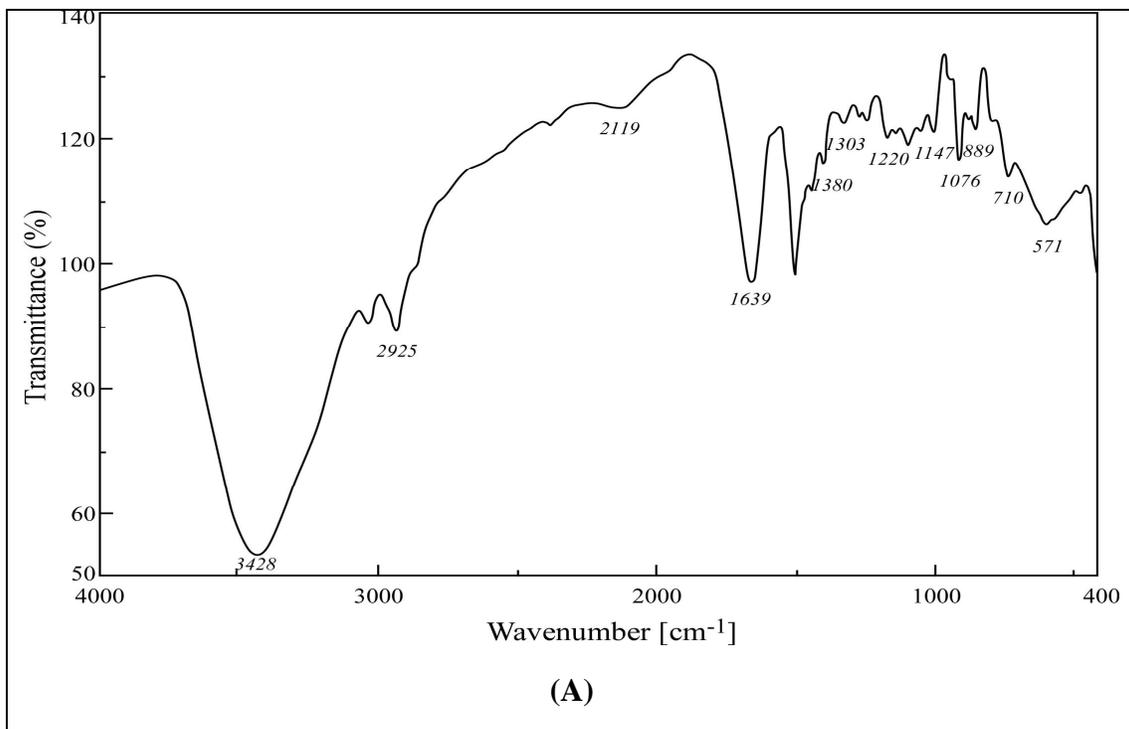


Fig.7 Infrared spectra of *P. sapidus* immobilized on Dowex®1×4 resin before (A) and after (B) biosorption of U(VI) ions



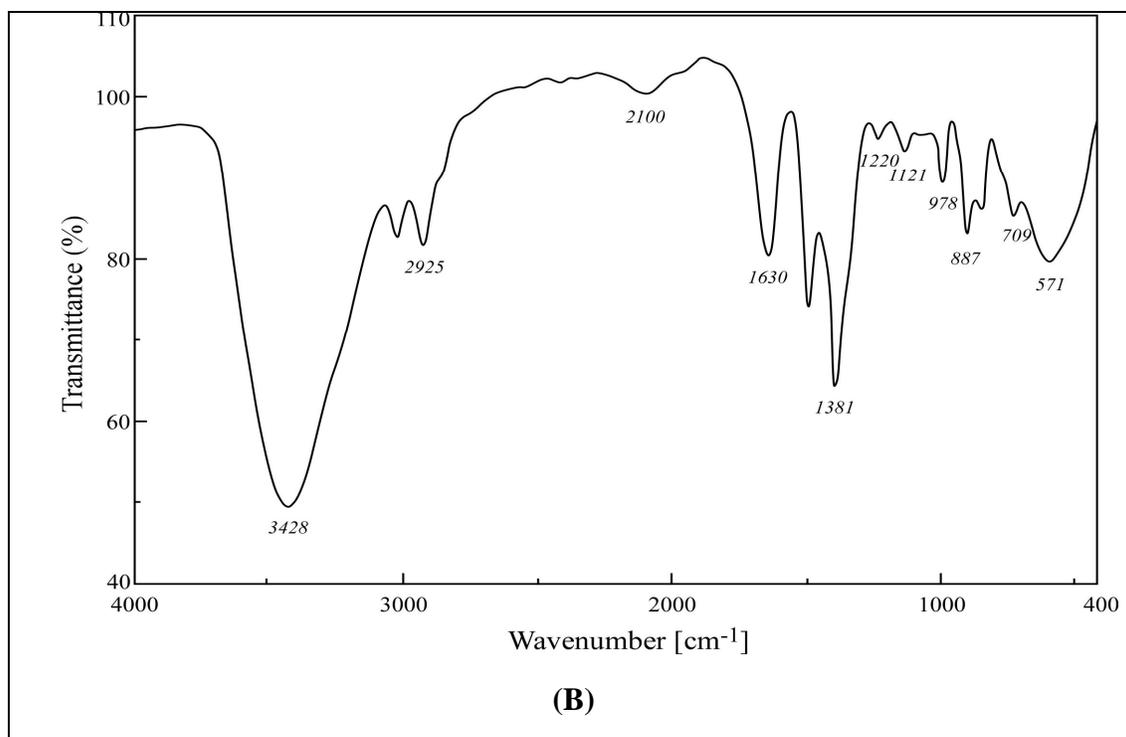
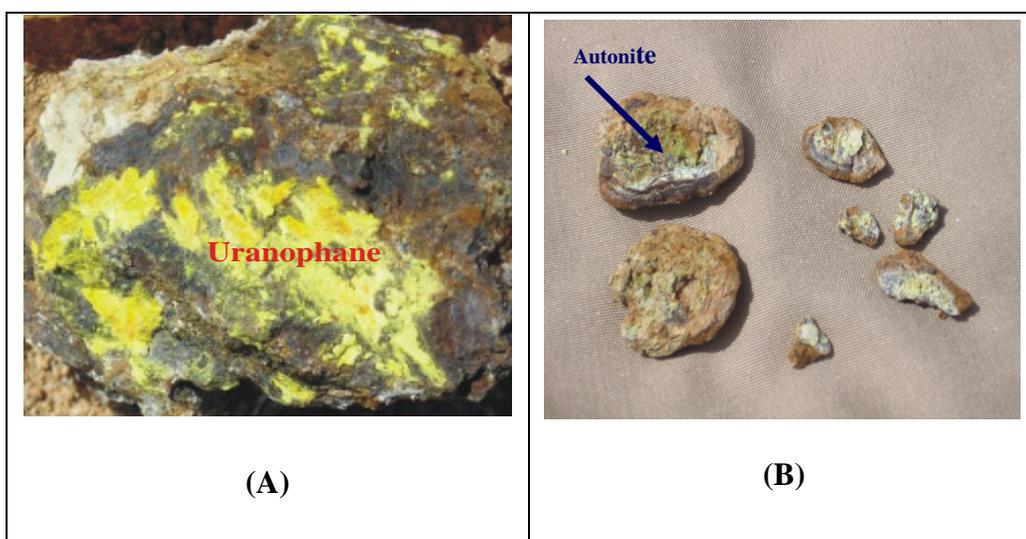


Fig.8 Stereo-photographs for uranophane (A) and autonite (B) separated from granitic rock of Gabal El Sela Area, South Eastern Desert of Egypt



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